A Permitting Framework for Class VI Geologic Sequestration Wells

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The Cadmus Group LLC

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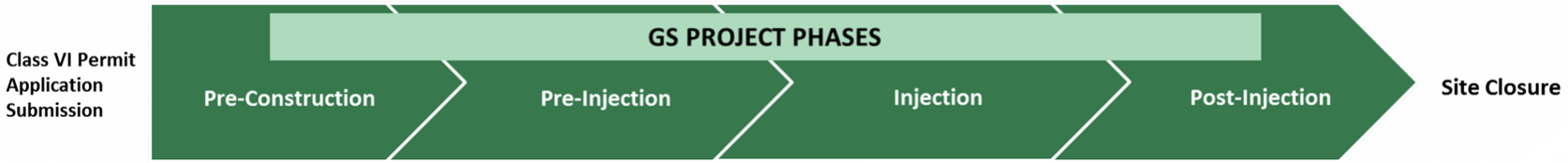
Class VI Requirements

- Class VI Permit Application Content
- Minimum Criteria for Siting
- AoR and Corrective Action
- Financial Responsibility
- Injection Well Construction
- Logging, Sampling, & Testing Prior to Operation
- Injection Well Operation
- Mechanical Integrity Testing
- Testing and Monitoring
- Reporting and Recordkeeping
- Injection Well Plugging
- Post-Injection Site Care (PISC) & Site Closure
- Emergency and Remedial Response
- Injection Depth Waivers

Goal of the Permit Application Review

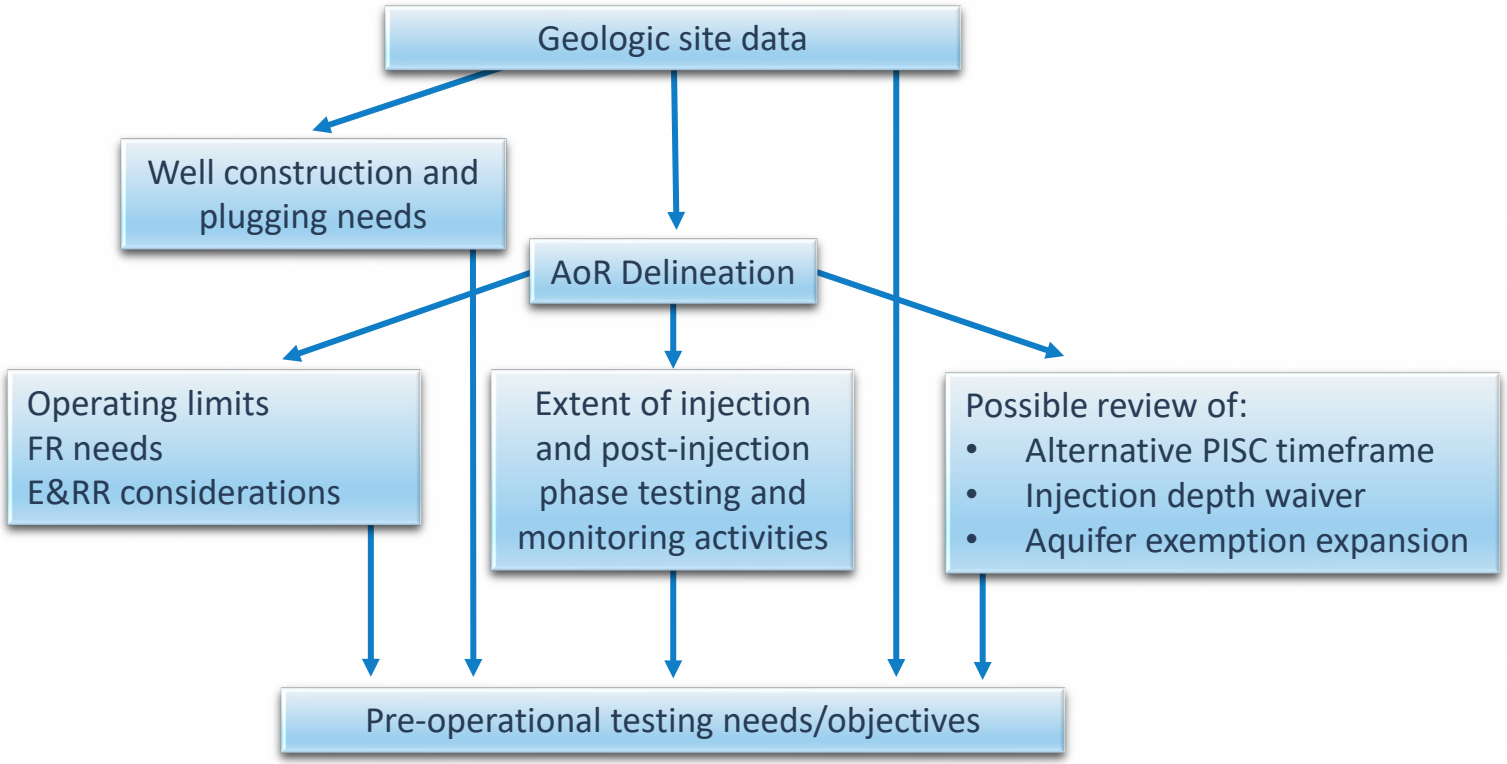


Multidisciplinary Review Team

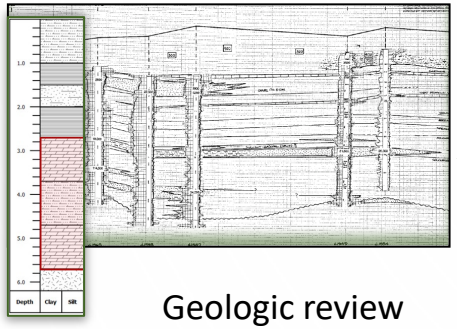
Complex, data-intensive Class VI permit applications need a detailed, multidisciplinary review

Geologic Site Characterization Information	Geologists, hydrogeologists, geochemists, log analysts
AoR Modeling	Environmental/reservoir modelers
Testing and Monitoring Plan	Geologists, hydrogeologists
Injection Well Construction and Plugging	Well engineers, log analysts/experts
Operating Conditions	Geologists, well engineers
FR Cost Estimates and Instruments	Finance experts, accountants, economists
Emergency and Remedial Response Plan	Risk analysts
Post-Injection Site Care and Site Closure	Geologists, modelers, engineers
Injection Depth Waivers & Aquifer Exemptions	Geologists, hydrogeologists, geochemists, modelers

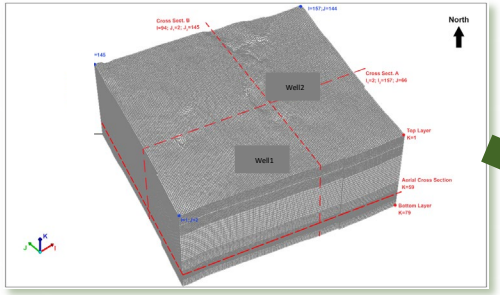
Relationship Across Topics



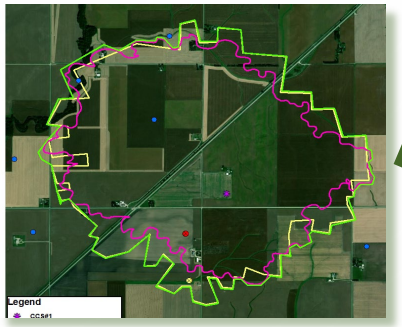
Conducting the Permit Application Review



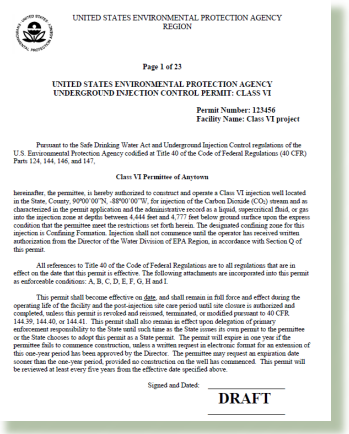
Geologic review



AoR modeling evaluation



Evaluation of project operations, testing & monitoring, etc.



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REGION

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
UNDERGROUND INJECTION CONTROL PERMIT: CLASS VI

Permit Number: 123456
Facility Name: Class VI project

Pursuant to the Safe Drinking Water Act and Underground Injection Control regulations of the U.S. Environmental Protection Agency codified at Title 40 of the Code of Federal Regulations (40 CFR) Parts 124, 144, 146, and 147,

Class VI Permittee of Anytown

hereinafter, the permittee, is hereby authorized to construct and operate a Class VI injection well located in the State, County, 90°00'00"N, -88°00'00"W, for injection of the Carbon Dioxide (CO_2) stream and as characterized in the permit application and the administrative record as a liquid, supercritical fluid, or gas into the injection zone at depths between 4,444 feet and 4,777 feet below ground surface upon the express condition that the permittee meet the restrictions set forth herein. The designated confining zone for this injection is Confining Formation. Injection shall not commence until the operator has received written authorization from the Director of the Water Division of EPA Region, in accordance with Section Q of this permit.

All references to Title 40 of the Code of Federal Regulations are to all regulations that are in effect on the date that this permit is effective. The following attachments are incorporated into this permit as enforceable conditions: A, B, C, D, E, F, G, H and I.

This permit shall become effective on date, and shall remain in full force and effect during the operating life of the facility and the post-injection site care period until site closure is authorized and completed, unless this permit is revoked and reissued, terminated, or modified pursuant to 40 CFR 144.39, 144.40, or 144.41. This permit shall also remain in effect upon delegation of primary enforcement responsibility to the State until such time as the State issues its own permit to the permittee or the State chooses to adopt this permit as a State permit. The permit will expire in one year if the permittee fails to commence construction, unless a written request in electronic format for an extension of this one-year period has been approved by the Director. The permittee may request an expiration date sooner than the one-year period, provided no construction on the well has commenced. This permit will be reviewed at least every five years from the effective date specified above.

Signed and Dated:

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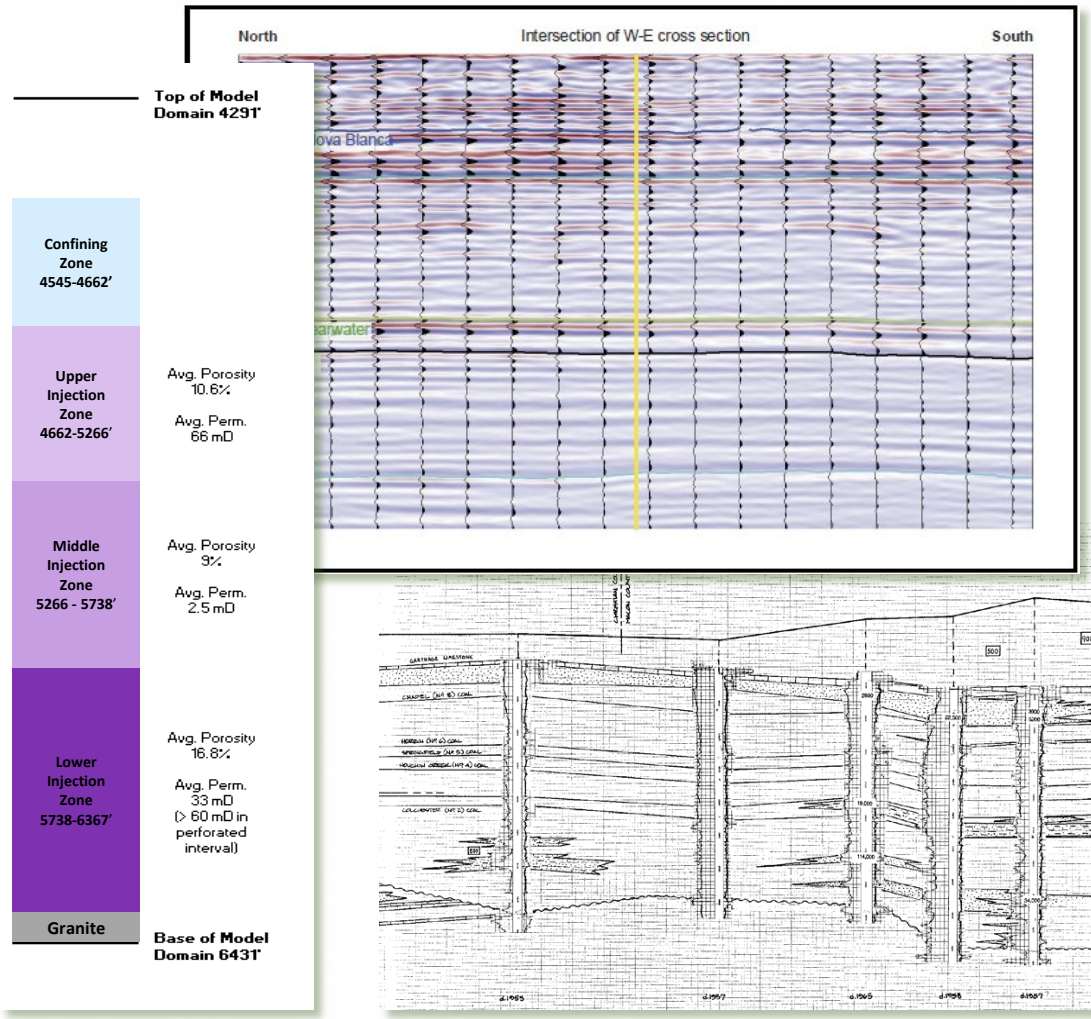
Permit

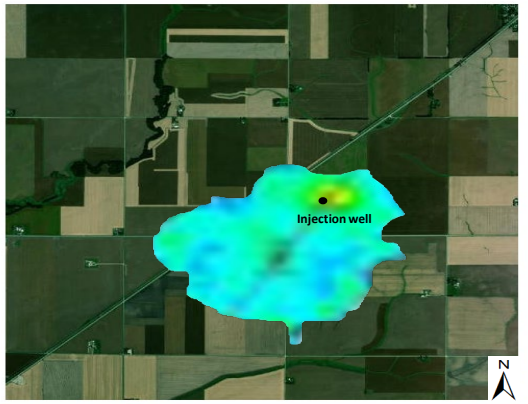
Evaluating Geologic Site Information

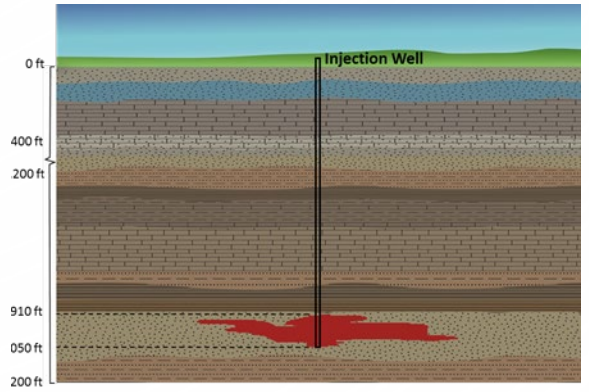


- Two phase review:
  - Geologic data review
  - Comprehensive evaluation of site-suitability

Reviewing AoR Modeling and the Proposed AoR Delineation and Corrective Action Plan

- Model selection
- Model design
- Parameterization
- Model outcomes
- Calibration & sensitivity analysis



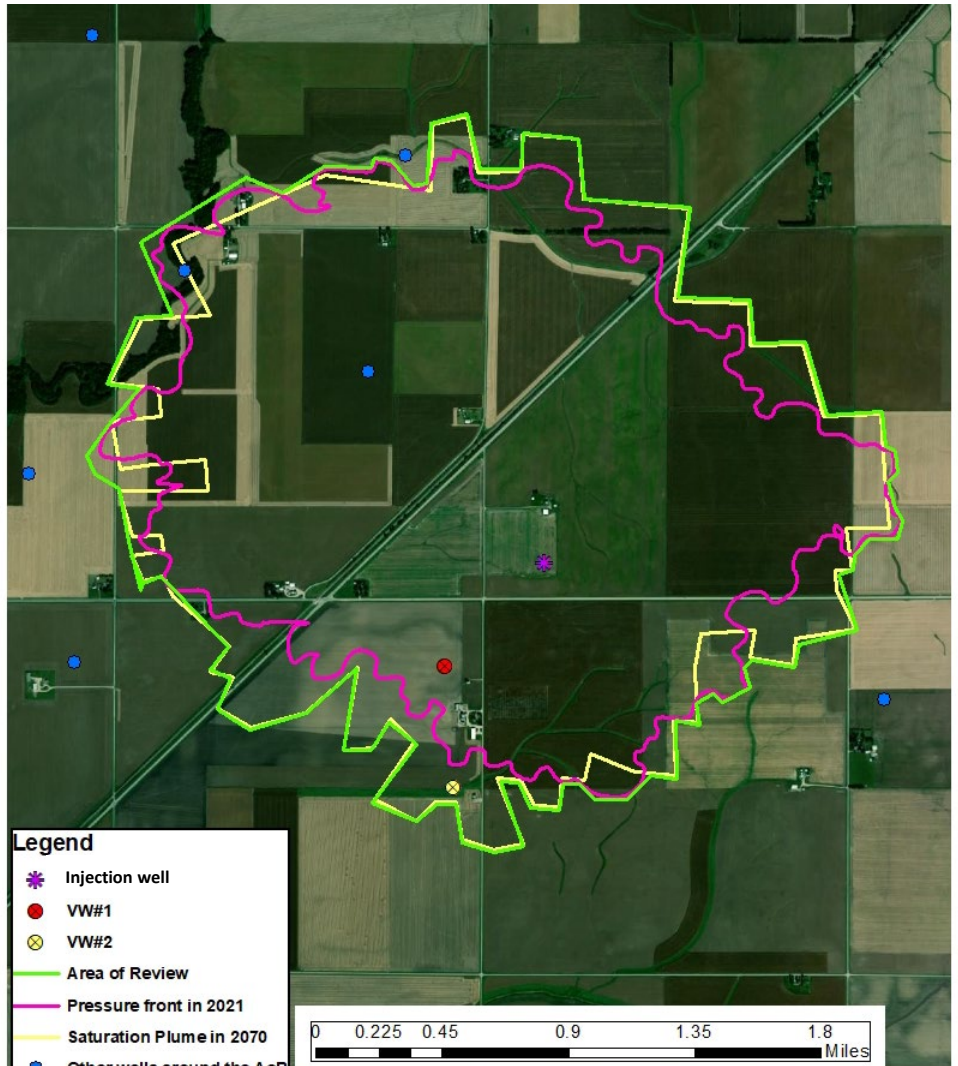


Reviewing Proposed Testing & Monitoring

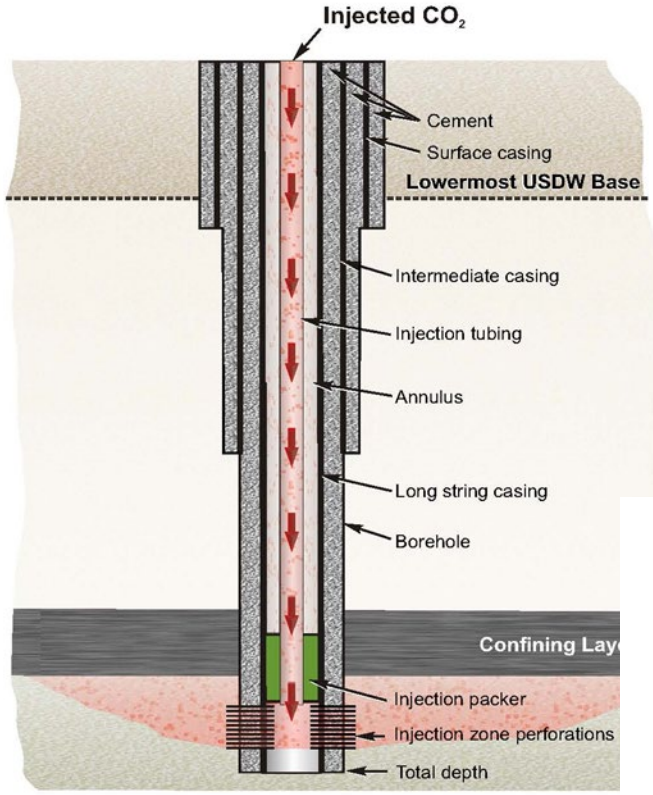
Comprehensive Testing and Monitoring Plan for:

- CO_2 stream monitoring
- MIT/corrosion monitoring of the injection well
- Pressure fall-off testing
- Groundwater quality monitoring
- CO_2 plume and pressure front tracking
- Soil/air or other monitoring (if needed)

Target Formation	Monitoring Activity	Monitoring Location(s)	Injection Phase Frequency
USDW	Geochemical monitoring (fluid sampling and analysis)	3 shallow monitoring wells • SW-1 (50 ft. bgs) • SW-2 (100 ft bgs) • SW-3 (200 ft bgs)	Quarterly
Above confining zone	Geochemical monitoring (fluid sampling and analysis)	Deep observation well • MS-33: 3634–3678 ft	Every 2 months
Injection zone	Water level/ pressure monitoring	Injection well • IW 1: 7888-9668 ft	Monthly (becoming weekly if induced pressures exceed 800 psi over background levels)
Multiple	2D seismic surveying	Surface stations	Once, approximately halfway through the injection period



Reviewing Well Construction, Operation, & Plugging Information



Note: figure is not to scale

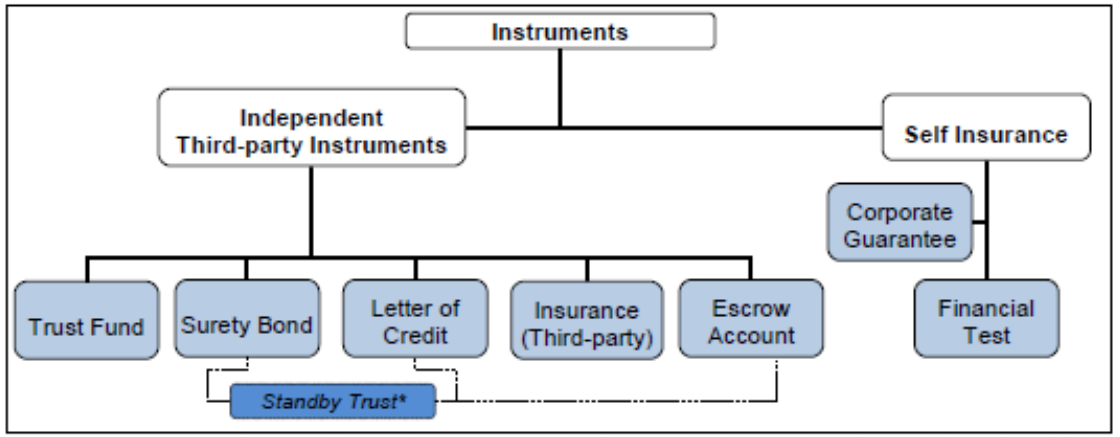
- Class VI unique considerations:
  - CO_2 compatibility/corrosion-resistant well design and plugging
  - Continuous cement to surface
  - Continuous monitoring equipment
  - Injection pressure

Proposed Injection Well Operating Conditions		
PARAMETER/CONDITION	**LIMITATION**	**UNIT**
Maximum Injection Pressure (1)	3,960	psig
Annulus Pressure (2)	400 minimum	psig
Annulus Pressure/Tubing Differential (3)	100 minimum	psig
Maximum CO_2 Injection Rate	1,000	metric tonnes/day

Notes:
(1) Injection pressure will be measured at the wellhead.
(2) Annulus pressure will be measured at the surface.
(3) Annulus pressure/tubing differential will be measured directly above the packer.

Reviewing Financial Responsibility Cost Estimates and Instruments

- Coverage for:
  - Corrective action
  - Well plugging
  - Post-injection site care & site closure
  - Emergency and remedial response
- Qualifying instruments are described in the rule

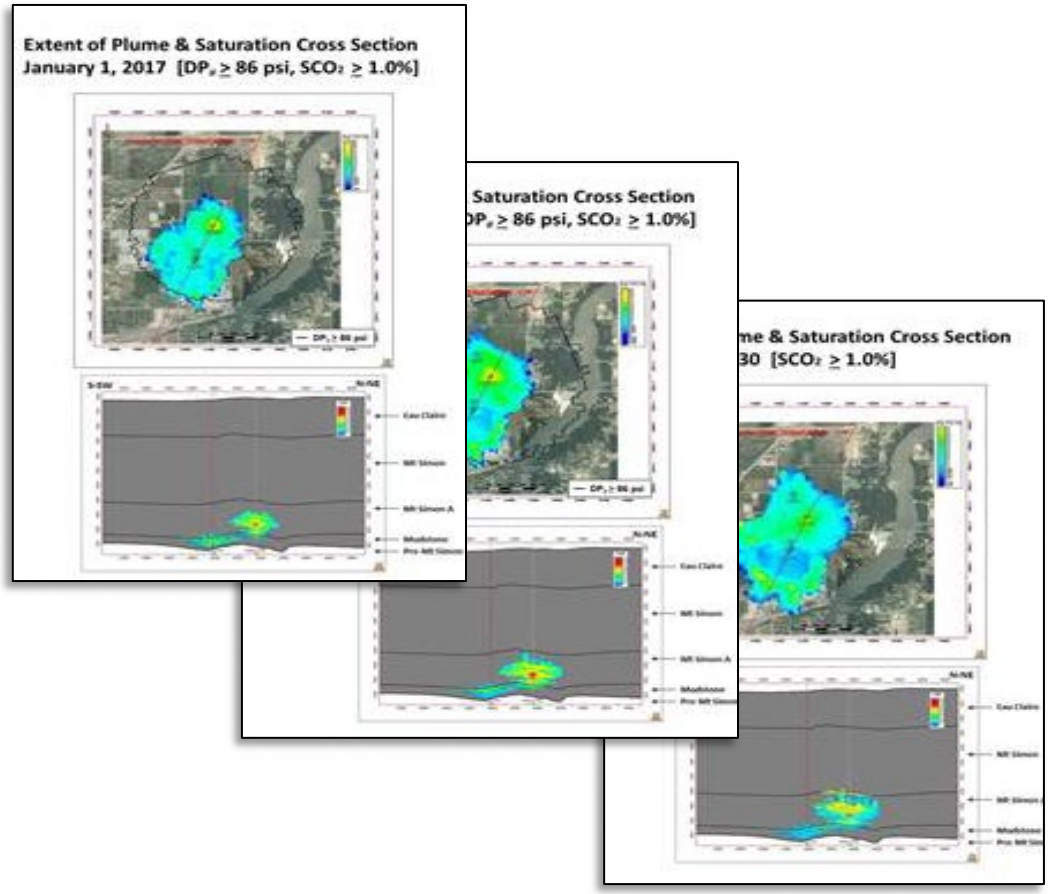


Reviewing the Proposed Emergency and Remedial Response Plan

- Risk Scenarios May Include:
  - Injection/monitoring well integrity failure
  - Injection well equipment failure
  - Fluid leakage to a USDW or the surface
  - Natural disaster
  - Induced seismic event
- For each scenario, address: likelihood/ timing of event; severity of the impact; avoidance measures; detection methods; and response personnel/equipment

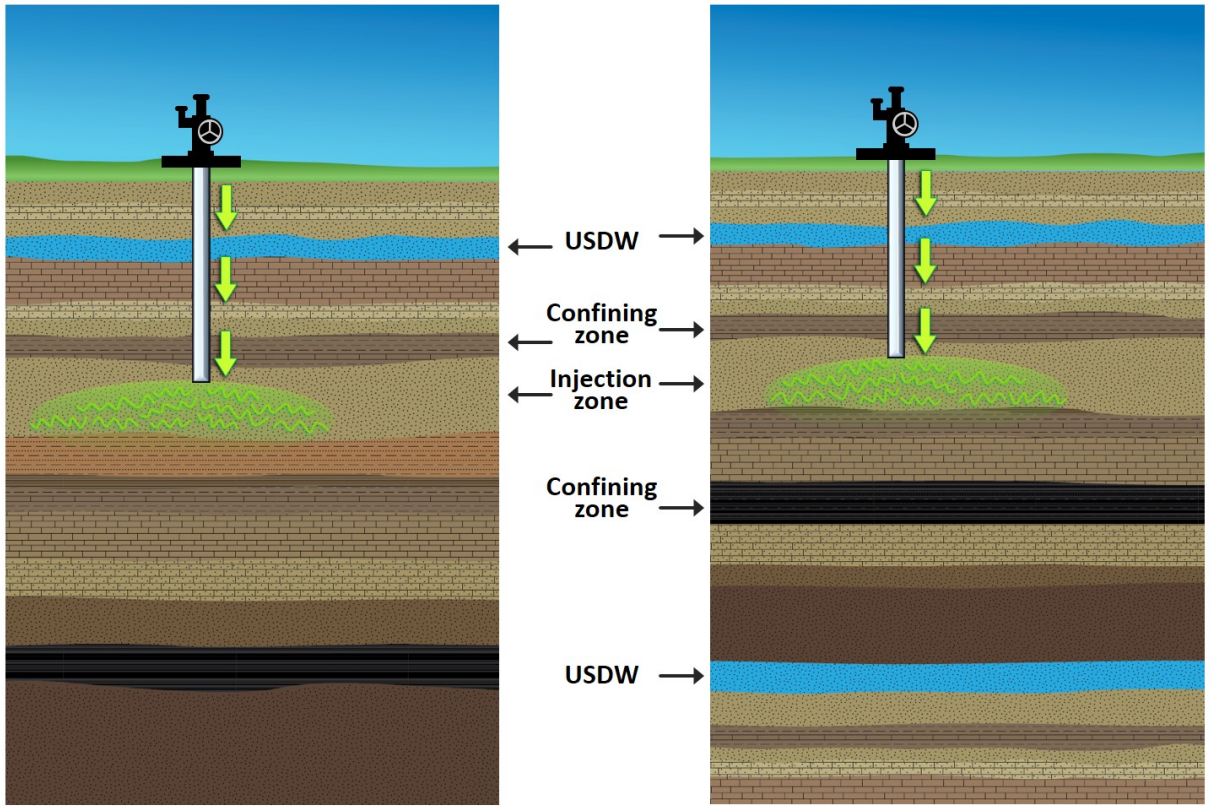
Local area map

Reviewing the Proposed Post-Injection Site Care and Site Closure Plan



- Pre- and Post-Injection Pressure Differential
- Predicted Position of the CO_2 Plume & Pressure Front at Site Closure
- Post-Injection Monitoring Plan
- Alternative Post-Injection Site Care Timeframe (if requested)
- Non-Endangerment Demonstration Criteria
- Site Closure Plan

Reviewing Injection Depth Waivers or Aquifer Exemption Expansions



Typical Class VI Well

Class VI Well Operating Under an Injection Depth Waiver

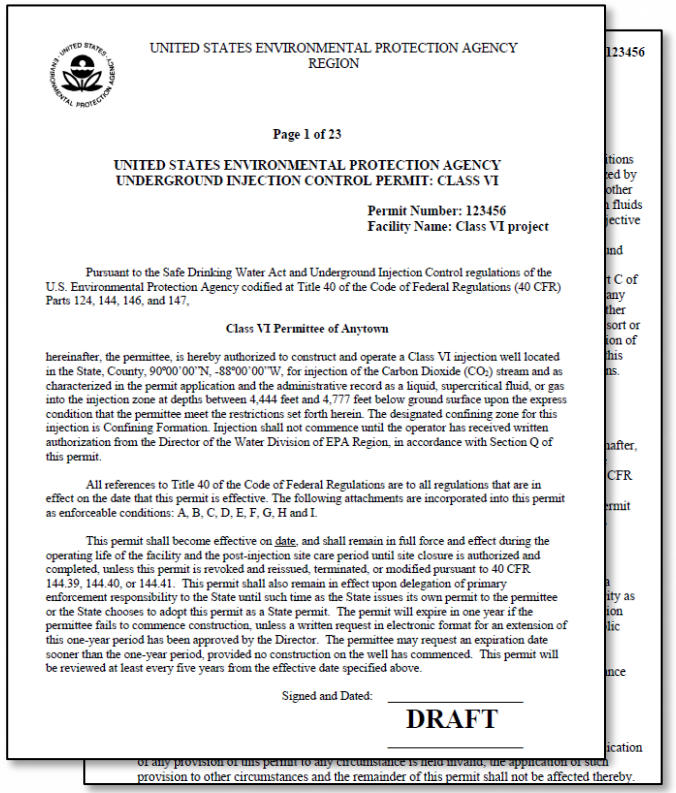
Note: *Figure not to scale*

Reviewing the Proposed Pre-Operational Testing Program

Pre-Operational Testing Objective	Methods/Tests in the Pre-Operational Testing Plan
Fault/fracture characterization	
Determine the position/sealing capacity of rea Faults	3D seismic surveys, core analyses
Injection/Confining Zone Characterization	
Confirm thicknesses and depths of the injection and confining zones	3D seismic surveys, collection/analysis of cores while drilling the injection & monitoring well
Geochemical Characterization	
Confirm the TDS of the injection zone	Sampling/analysis during drilling
Identify lowermost USDW	Sampling/analysis during drilling
Geomechanical/Petrophysical Characterization	
Gather data on capillary pressure, and information on fractures, stress, ductility, rock strength, elastic properties, in situ fluid pressures	Core analyses, including: fracture analysis, triaxial compression testing, etc.
Seismic Evaluation	
Evaluate seismic history and seismic risk	Dipole sonic logs, formation microimager logs, and micro-seismic monitoring
CO_2 Stream Compatibility	
Generate fluid chemistry and mineralogic data, pressure, temperature, and pH conditions at depth to provide inputs to the geochemical modeling	Analysis of water and core analyses

Outcome of the Permit Application Review

- Class VI permit and attachments:
  - Project plans for AoR and Corrective Action, Testing and Monitoring, Well Plugging, PISC and Site Closure, and Emergency and Remedial Response
  - Operating conditions
  - Well construction and pre-operational testing
  - Financial responsibility demonstration
  - Stimulation plan
- Reports documenting significant evaluations for the administrative record



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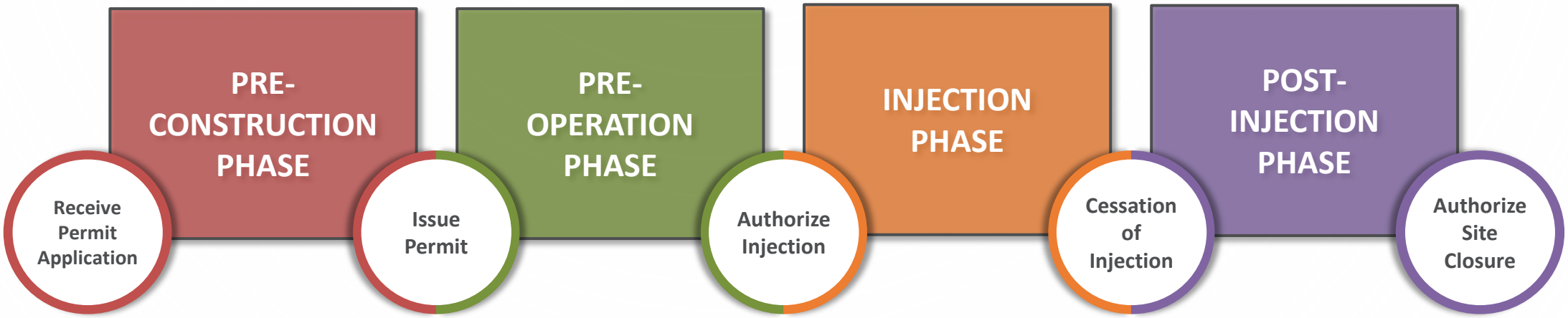
provision to other circumstances and the remainder of this permit shall not be affected thereby.

Beyond Permit Issuance



Thank You!

Questions?

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