EXHIBIT 4

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FutureGen™ ALLIANCE

Clean Energy for a Secure Future

FutureGen
Initial Conceptual Design Report

May 2007

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5.0 SITE SELECTION FOR THE FUTUREGEN PROJECT

5.1 Introduction to Site Selection

This section describes the process of selecting the preferred site for the FutureGen project, summarizes the key selection criteria, and shows how each of the four site candidates meets these criteria. This section also reviews how the sites will be reduced to a final selection with alternatives. The site identification process (Figure 5.1) considered 12 proposals (Figure 5.2) and resulted in four sites (IL-Mattoon, IL-Tuscola, TX-Odessa and TX-Brazos) advancing to the candidate site list.

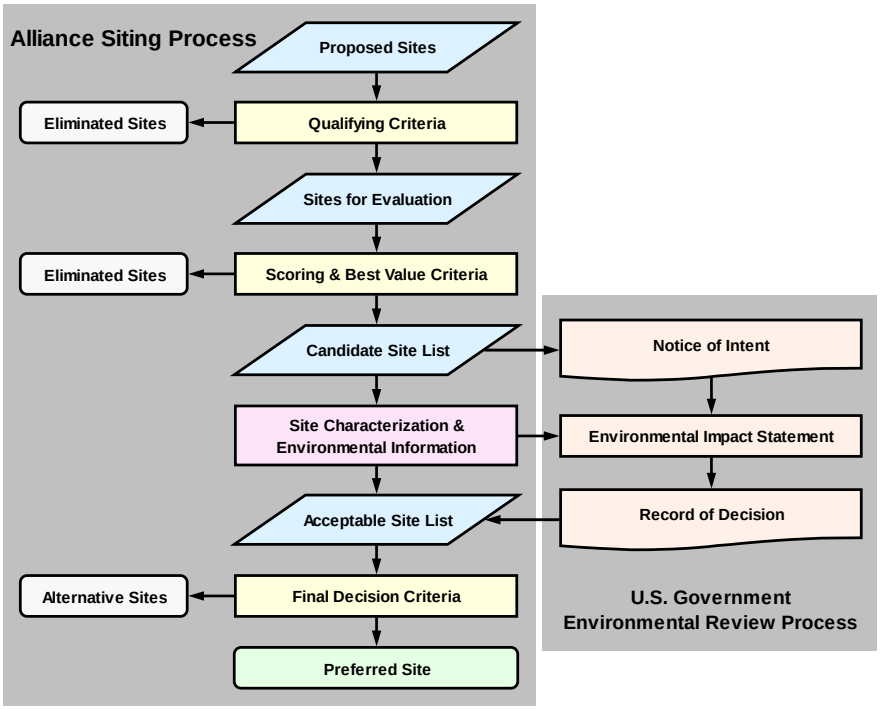


Figure 5.1. FutureGen Siting Process

5.1.1 Selection criteria

Beginning in December 2005, the Alliance siting team developed a set of criteria that was issued in the Request for Proposals for the FutureGen facility. These criteria included safety, injection rate and capacity, and accessibility for monitoring requirements. They were established to maximize the opportunity for success of the project, while adhering to FutureGen's core goals, which include demonstration of CO_2 capture and storage technologies in geologic formations common throughout the world. Three types of criteria were developed:

- Qualifying criteria – criteria that each site must meet to be considered further, (Figure 5.3)
- Scoring criteria – criteria that would allow sites to be ranked based on the extent to which they possessed desirable features (Figure 5.4)
- Best value criteria – criteria that would allow the Alliance to maximize the opportunities to meet the project's goals and that would minimize risk to the project.

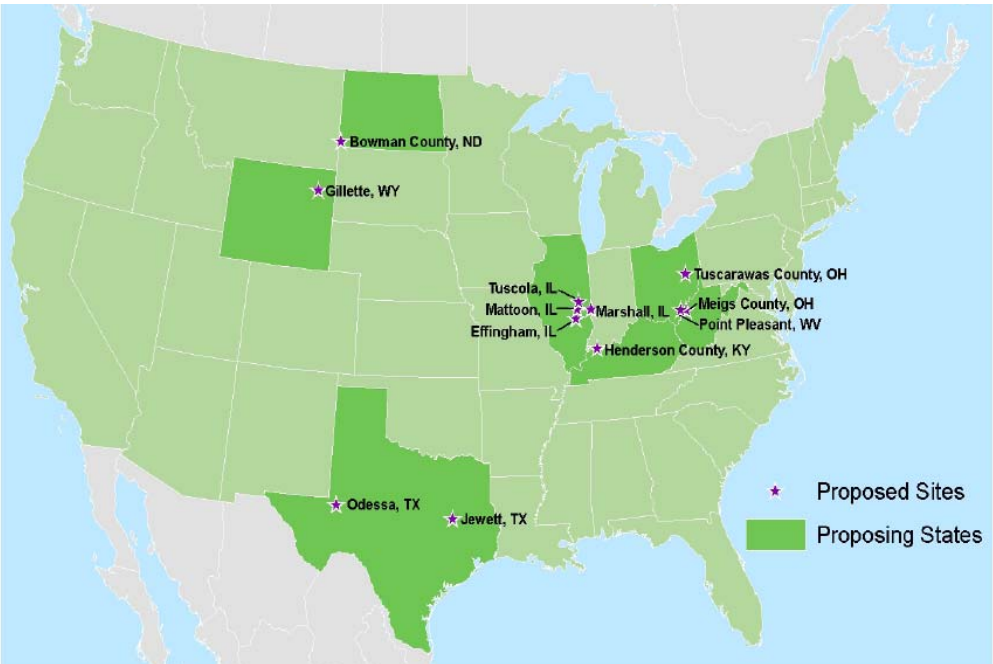


Figure 5.2. Map of Offered Sites: Twelve Sites were Proposed in Seven States

These criteria were further revised, based on comments from the Alliance's subsurface Technical Experts Group, drawn from experts in the field of CO_2 geologic storage.

Following the review of the original proposals and responses to clarifying questions asked of each site, evaluation teams determined that four sites did not satisfy all of the qualifying criteria. These four sites – Bowman County, North Dakota; Meigs, Ohio; Point Pleasant, West Virginia; and Gillette, Wyoming – were eliminated from the siting process.

The Subsurface Proposal Evaluation Team, together with members of the Subsurface Technical Experts Group, scored the remaining eight sites against the Subsurface Scoring Criteria, using methods that had been determined in advance of receipt of the proposals. These scoring criteria were generated to rank sites by their potential for injection and storage of large quantities of CO_2 in a safe surface and subsurface environment, and by their potential for transferable research on fate and transport of CO_2 in a variety of rock types. The evaluation teams determined each site's score for each criterion, and these scores were used to calculate a final total score for each site. This resulted in a list of sites, ranked according to their suitability for geologic storage. This was combined with the ranked list of power plant sites to generate a final ranked list of qualified sites.

The scoring results for the eight remaining sites are shown in Table 5.1, and are graphically summarized in Figure 5.5. Scores ranged from 255 to 395. During the scoring process, all 12 proposed sequestration sites received field visits by an independent three-person team. None of the team members had knowledge of the scoring process to ensure an unbiased set of site visits. This team used a standardized set of questions to review features of the sequestration site, including physiography, land use, physical access, sensitive receptors, and background sources of CO_2. These site visits confirmed the information in the proposals, identified additional information, and were used to inform the Alliance's consideration of the best value criteria.

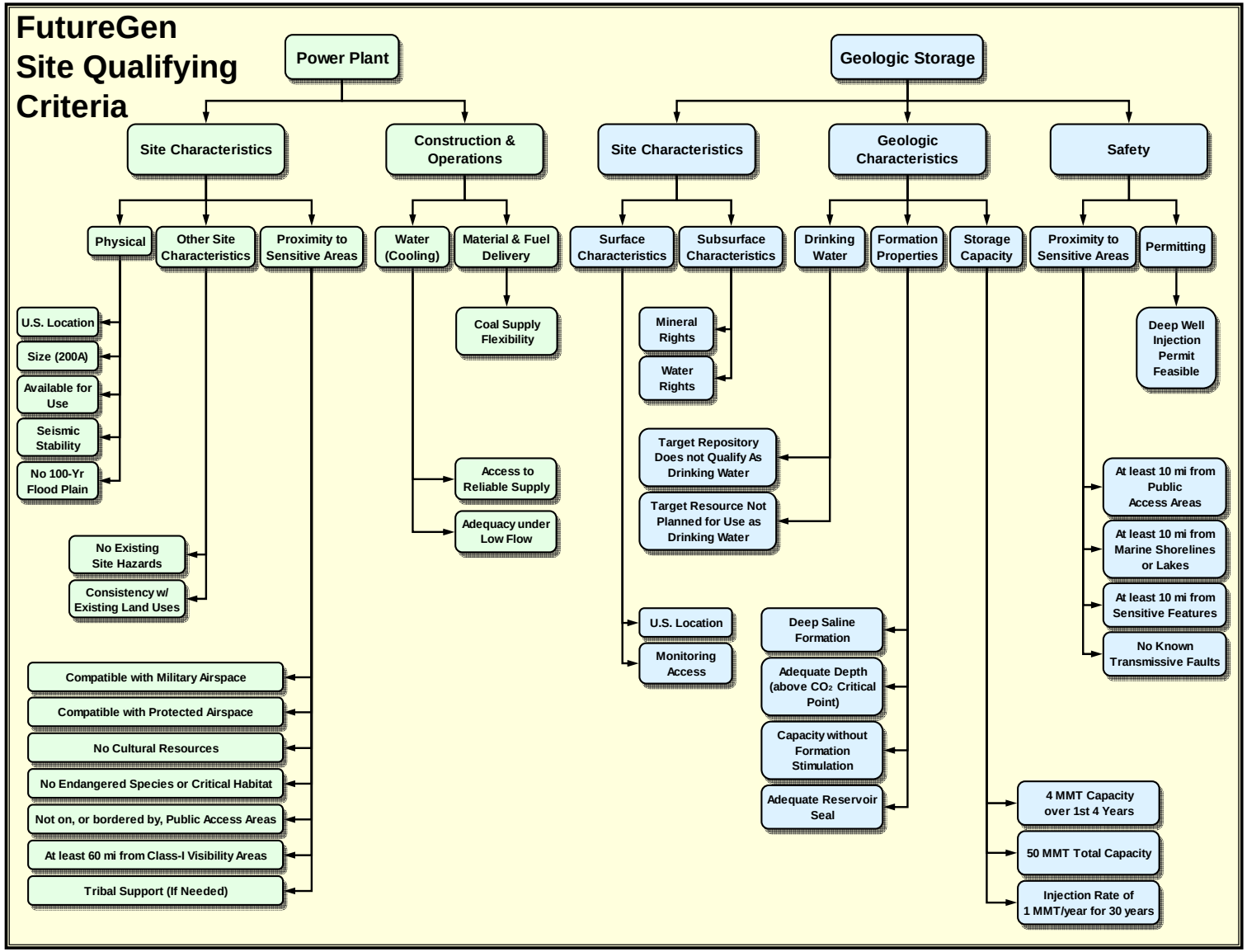


Figure 5.3. FutureGen Qualifying Criteria

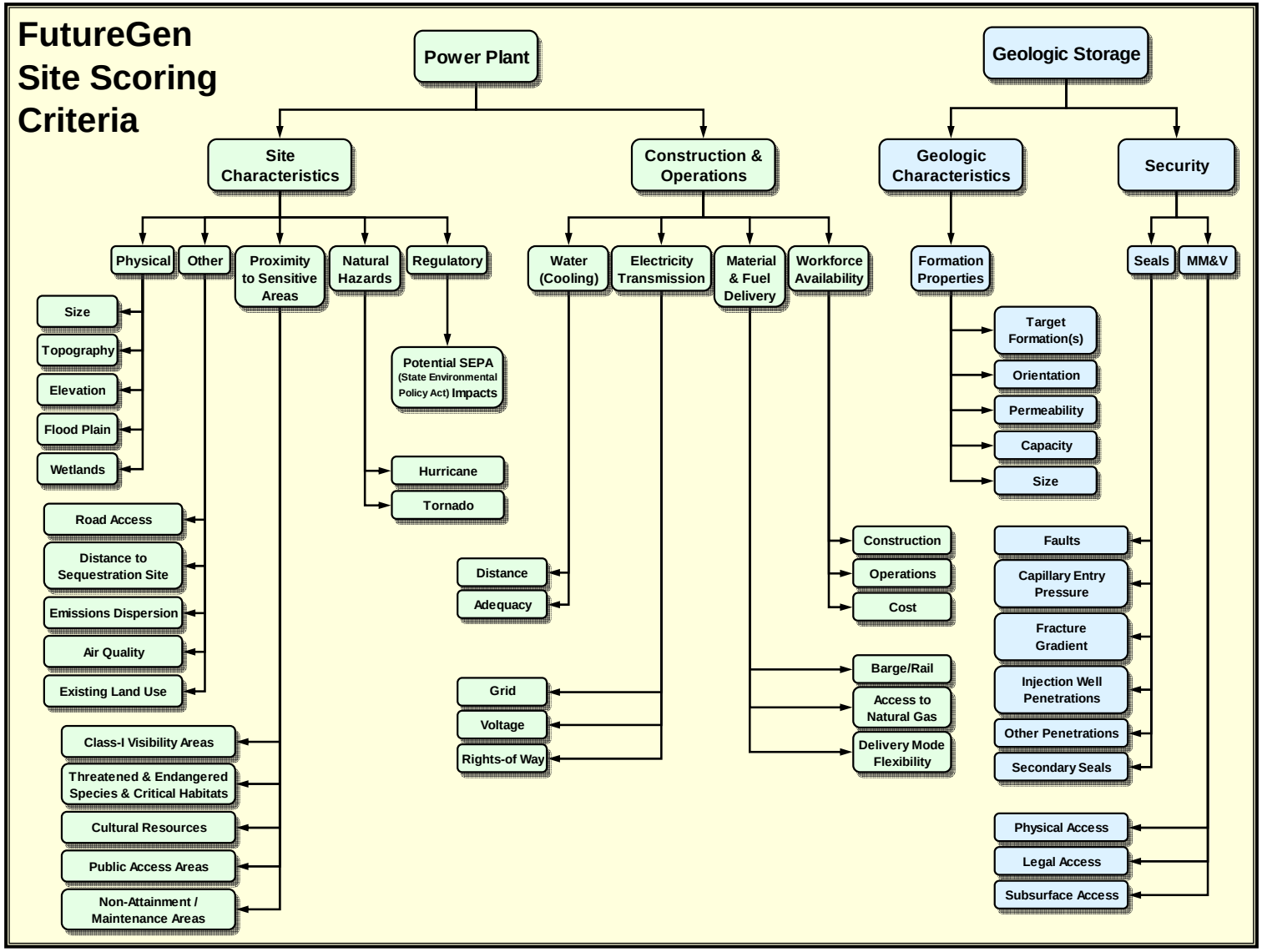


Figure 5.4. FutureGen Scoring Criteria

Table 5.1. Scoring Results for Sites Meeting Qualifying Criteria

Selection Criteria	TX-Odessa	IL--Mattoon	TX Brazos	IL--Effingham	IL--Tuscola	IL--Marshall	OH--Tuscola	Kentucky
Formation Properties								
Target Formations	40	20	40	20	20	20	40	40
Orientation (Dip)	25	15	25	25	25	25	25	25
Permeability	5	25	15	25	25	25	15	15
Capacity	15	25	15	25	25	25	15	5
Plume Size	25	25	25	25	25	25	15	5
Subtotal	**110**	**110**	**120**	**120**	**120**	**120**	**110**	**90**
Formation Seals								
Faults	50	50	30	50	30	50	50	30
Capillary Entry Pressure	30	10	30	10	10	10	10	10
Fracture Gradient	10	30	10	30	30	30	10	10
Injection Well Penetrations	15	25	25	25	25	25	5	15
Other Penetrations	15	25	5	25	25	25	5	25
Secondary Seals	15	25	15	25	15	25	15	25
Subtotal	**135**	**165**	**115**	**165**	**135**	**165**	**95**	**115**
MM&V Considerations								
Physical Access	50	50	50	30	50	10	10	10
Legal Access	50	10	50	10	10	10	10	10
Subsurface Access	50	50	50	50	50	50	50	30
Subtotal	**150**	**110**	**150**	**90**	**110**	**70**	**70**	**50**
Grand Total	**395**	**385**	**385**	**375**	**365**	**355**	**275**	**255**

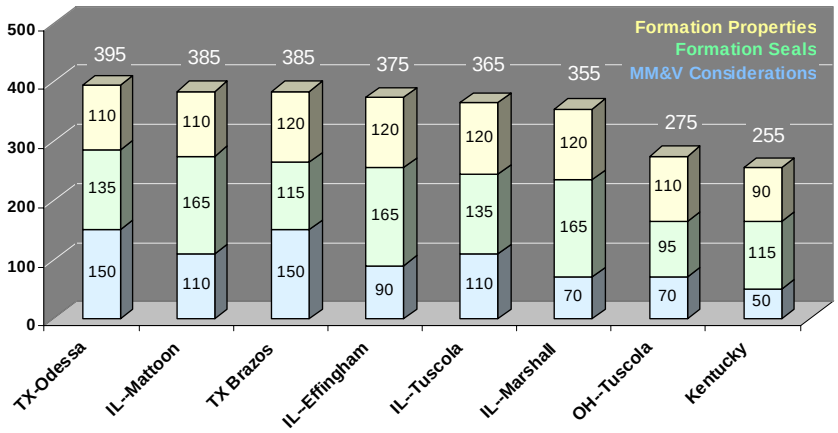


Figure 5.5. Scoring Results for Sites Meeting Qualifying Criteria

Once the scores were established, then the site performance against the best-value criteria was assessed to get a final ranking, as follows:

Texas-Heart of Brazos

There are no residences above the proposed target formation, and Texas has agreed to assume title to and liability for the CO_2 produced. There are good quality data available for both surface and subsurface conditions. The net effect of the best value criteria was to strengthen the standing of this site following the initial scoring.

Illinois-Mattoon

The site offeror demonstrated the ability to obtain the necessary surface and subsurface rights in a timely manner. This includes rights-of-way needed for transmission lines and water, gas, and CO_2 pipelines. The net effect of the best value criteria was to strengthen the standing of this site following the initial scoring.

Texas-Odessa

The site offeror demonstrated the ability to obtain all surface and subsurface rights in a timely manner. There are no residences above the proposed target formation, and Texas has agreed to assume title to and liability for the CO_2 produced. There are good quality data available for both surface and subsurface conditions. The net effect of the best value criteria was to strengthen the standing of this site following the initial scoring.

Illinois-Effingham

While it was the fourth highest scoring site, this site poses substantial constructability problems. There are two housing developments located within one mile of the power plant site (and the onsite CO_2 injection well), and part of the water source for the plant would be public drinking water. The net effect of the best value criteria was to weaken the standing of this site following the initial scoring.

Illinois-Tuscola

As fifth highest scoring site, the site offeror demonstrated the ability to obtain surface rights in a timely manner. The net effect of the best value criteria was to strengthen the standing of this site following the initial scoring.

This final ranking then generated the candidate list of four sites: Texas-Odessa, Illinois-Mattoon, Texas-Heart of Brazos, and Illinois-Tuscola. All four sites offer the potential for safe, permanent geologic sequestration of CO_2 and additionally are proximal to petroleum fields that potentially could use large volumes of CO_2 in oil and gas enhanced recovery programs.

5.1.2 Final Site Selection criteria

Pending the Department of Energy's preparation of an Environmental Impact Statement for each of the four candidate sites, and issuance of a subsequent Record of Decision (ROD) listing those sites deemed acceptable to DOE at the end of the EIS process, the Alliance will select a final site and alternative site(s). Should the final site be found unsuitable for any reason after further site characterization, an alternative site would then be selected. The Alliance will weigh issues such as feasibility, cost, and risk in identifying the final site, and this selection will be based upon best-value criteria as well as input from independent technical experts.

5.2 FutureGen Facility Permitting

The FutureGen facility will need a variety of permits prior to beginning operation. Securing necessary permits and performing necessary consultations are critical path activities for the success of the FutureGen facility. Most of the permits will need to be issued by the applicable state environmental regulatory agency.

Most of the basic permits will be same whether the facility is sited in Illinois or Texas. However, some details of permit application will differ because of differences in state regulatory requirements or because of particular characteristics of the chosen site. The required permits and approvals for a FutureGen facility sited in Illinois or Texas that have been identified at this preliminary stage of FutureGen development are shown in Table 5.2. Additional information is provided in the *Draft Permitting Requirements* report in Volume 2, Appendix D.

Table 5.2. Preliminary FutureGen Facility Permit and Approval Requirements

Illinois	Texas
Environmental Impact Statement	Environmental Impact Statement
Consultation under the National Historic Preservation Act	Consultation under the National Historic Preservation Act
Endangered Species Act Consultation	Endangered Species Act Consultation
State Endangered Species and Natural Areas Review	
Prevention of Significant Deterioration (PSD) Permit	Prevention of Significant Deterioration (PSD) Permit
State Air Construction Permit (if PSD permit is not needed)	State Air Construction Permit (New Source Review), Standard Permit, or Air Permit by Rule
Federal Clean Air Act (CAA) Operating Permit	Federal Clean Air Act (CAA) Operating Permit
State Air Operating Permit (if an operating permit under the CAA is not needed)	
Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR) compliance	Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR) compliance
CAA Acid Rain Permit	CAA Acid Rain Permit
NPDES General Permit for Stormwater Discharges Associated with Construction	TPDES General Permit for Stormwater Discharges Associated with Construction
NPDES General Permit for Stormwater Discharges Associated with Industrial Activity	TPDES General Permit for Stormwater Discharges Associated with Industrial Activity
Pretreatment Authorization for Discharge of Wastewater to Municipal Collection System (if discharge)	Sludge Use or Disposal from Wastewater Treated Onsite may require a TPDES permit
Permit for Groundwater Monitoring Wells	Permit for Groundwater Withdrawal (if located in a Groundwater Control District) and Monitoring Wells
Hydrostatic Test Water Discharge Permit	Hydrostatic Test Water Discharge Permit
	Surface Casing Letter from the Railroad Commission of Texas (RRC) for Texas Commission on Environmental Quality (TCEQ) UIC Wells. Surface Casing Letter from TCEQ for RRC UIC Wells.
Septic Permit (if onsite sewage facility)	Septic Permit (if onsite sewage facility)
Building Permit	Building Permit
Permit for Nonhazardous Onsite Waste Disposal Facility	
Interconnection Agreement	Interconnection Agreement
Notice to the Federal Aviation Administration of Proposed Construction	Notice to the Federal Aviation Administration of Proposed Construction
Certificate of Public Convenience and Necessity	
Potable Water Supply Connection Permits	
Farmland Conversion Impact	
State Wetland Review	
Natural Gas Pipeline ROW	
Transmission Line ROW	Transmission Line ROW
Water Pipeline ROW (if needed)	Water Pipeline ROW (if needed)
CO2 Pipeline ROW	CO2 Pipeline ROW
	Registration with the Public Utility Commission of Texas
UIC Permit	UIC Permit

The key permits that are likely to be needed at each site are a new source review/prevention of significant deterioration permit for air emissions, an underground injection control (UIC) permit, and a national pollutant discharge elimination system (NPDES) permit for wastewater discharges.

One goal of the FutureGen facility is for the facility to have near-zero emissions. If near-zero emissions could be achieved through startup and the entire operating life of the facility, it is possible that no air related permits would be needed for the plant. Achieving near-zero emissions during the entire plant operating life, however, is probably unrealistic, and one or more air permits are likely to be needed. To the extent emissions can be reduced and kept below threshold levels, however, the air permitting process can be made easier and less complex.

EPA's current position is that a UIC Class V experimental technology well subclass best provides a mechanism through which EPA may generally permit pilot CO_2 injection geologic sequestration projects.

The NPDES permit conditions will depend on the constituents of the wastewater from the facility and the location of wastewater disposal. DOE will need to take several permitting/consultation-related actions regardless of which of the four remaining candidate sites is chosen for a FutureGen facility. These actions include:

- Preparation of an environmental impact statement (EIS) consistent with Section 102(2)(C) of the National Environmental Policy Act (NEPA) and the DOE NEPA implementing regulations at 10 CFR 1021
- Consultation with the U.S. Department of the Interior Fish and Wildlife Service to fulfill DOE's responsibility under Section 7 of the Endangered Species Act to ensure that any action authorized, funded, or carried out is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of critical habitat of such species
- Consultation with the Illinois Historic Preservation Agency and/or the Texas Historical Commission to fulfill DOE's responsibility under Section 6 of the National Historic Preservation Act to take account of the FutureGen project on historic properties
- For the two proposed agricultural sites in Illinois, following the procedures in 7 CFR 658 to ensure compliance with the Farmland Protection Policy Act.

To expedite the FutureGen facility permitting process, the Alliance will:

- Consult with permitting agencies well in advance of submitting the permit application. Such consultation will help clarify the expectations of the permitting agency and give the agency an opportunity to plan for processing the application.
- Make sure the permit application is complete. Submission of incomplete information will likely increase the processing time.
- To the extent possible, submit permit applications concurrently to reduce the total permit processing time.
- Prepare and update as appropriate, a permitting work plan and tracking schedule. Such a plan and schedule can aid understanding of the permitting process and help to ensure that needed permitting actions are achieved in a timely manner.

6.0 GEOLOGIC SUMMARY DESCRIPTION OF CANDIDATE SITES

This section summarizes the geology, proposed injection schemes, well bore layout, and monitoring plan for each of the four candidate sequestration sites. It also identifies uncertainties in the subsurface data and describes future investigations needed to reduce these uncertainties.

Each of the four sites is well qualified for the safe and effective geologic sequestration of CO_2. All have thick, heterogeneous saline target formations, competent regional seals, and are capable of accepting the CO_2 output of the FutureGen facility during the lifetime of the project.

6.1 Mattoon

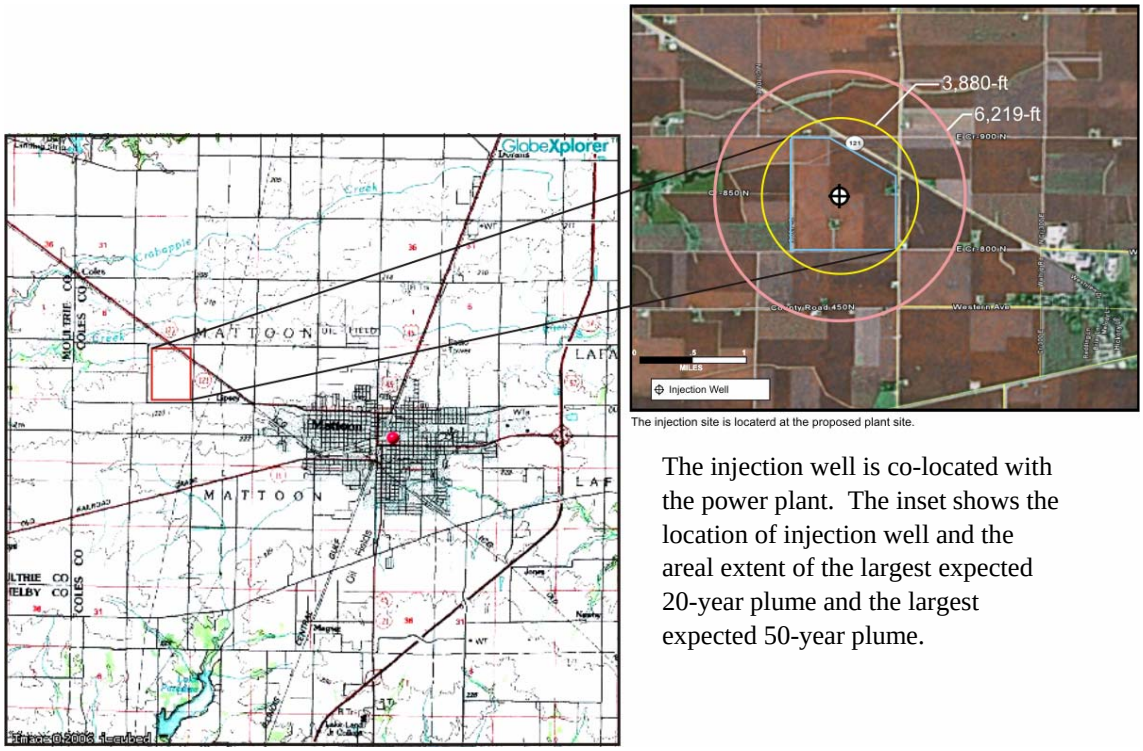
The Mattoon site (Figure 6.1) is located in a semi-rural area, one mile northwest of the small town of Mattoon, in Coles County, east central Illinois. The proposed injection site is co-located on the proposed power plant site. The injection reservoir is the Mt. Simon Sandstone, a regional deep saline formation that occurs over several states, with thicknesses up to 2000 feet. The Mt. Simon at the Mattoon site is estimated to be between 1300 and 1600 feet thick consisting of stacked thin porous sandstones, separated by thin, less permeable, siltstones and shales. The thick (500-foot) siltstones and shales of the Eau Claire formation form the primary seal, and immediately overlie the Mt. Simon. The Eau Claire also extends over several states. The Mattoon site lies in a gentle syncline between two oil fields (Figure 6.2). No known wells penetrate the primary seal. Figure 6.3 shows the Mattoon lithologies, including seals (blue), primary and optional injection zones (yellow), and well design for two Mattoon wells: a primary injector and a back-up well. The primary injection zone is the Mt. Simon; an optional injection reservoir is the 200-foot thick St Peter Formation. Both targets are quartz sandstones.

Numerical modeling by Battelle supports the site offeror's calculations that at least 50 MMT of CO_2, injected at a constant rate of 2.5 MMT per year for twenty years, can be handled by a single injection well in the Mt. Simon formation. This holds even if the reservoir is two-thirds thinner than expected. Across a range of modeled injection scenarios, the largest projected 20-year plume occurs in a scenario where 2.5 MMT is injected for twenty years. This 20-year plume size is approximately 1086 acres[5], which corresponds to a plume radius of approximately 3880 feet (0.73 miles). After injection ends, this plume continues to expand. After 50 years, model results suggest it expands up to 1880 acres, which corresponds to a plume radius of approximately 5105 feet (0.97 miles). At an alternative injection rate of a constant 1 MMT/yr for 50 years, model results suggest that the 50-year plume will have a radius of 6219 feet (1.18 miles) and an area of 2789 acres. This is the largest 50-year plume across all modeled injection scenarios.

A proposed backup well will provide capacity during outages, such as injection well inspections and tests. The Mattoon site requires only short pipeline runs from the plant, has good apparent thickness of the reservoir, a relatively simple injection scheme and MM&V requirement. However, because of lack of local subsurface data, this site has considerable uncertainty in reservoir properties, and the MM&V program (detailed in the Volume 2 *Carbon Dioxide Storage Study*) will be modified if previously unidentified wellbores or other hazards are discovered during pre-injection site characterization.

The subsurface data submitted for both Illinois sites (Mattoon and Tuscola) are virtually identical, except for details on estimated depth and thickness. The Mt. Simon at Mattoon is deeper—the base of the Mt. Simon is estimated to be 8350 feet at Mattoon and 7750 feet at Tuscola. The depth is of moderate

[5] The cited plume area includes 95% of the mass of the CO_2 plume.



The injection well is co-located with the power plant. The inset shows the location of injection well and the areal extent of the largest expected 20-year plume and the largest expected 50-year plume.

Figure 6.1. Location of the Mattoon Injection Site

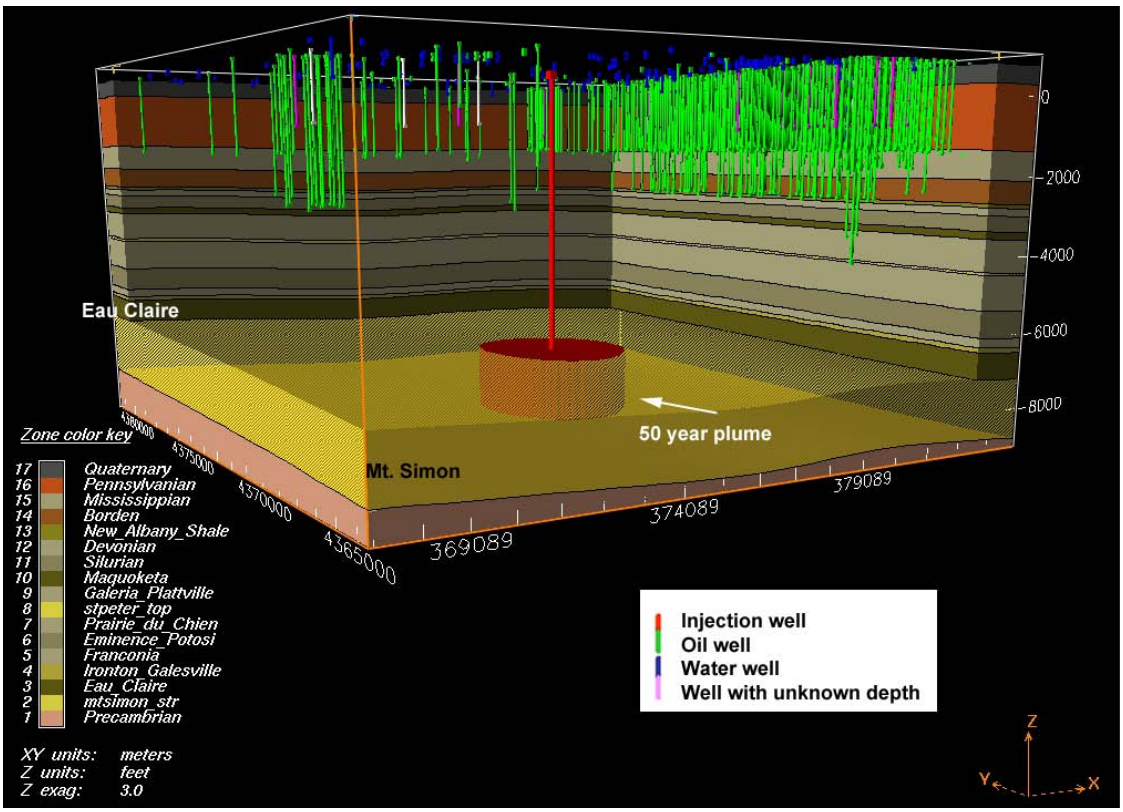


Figure 6.2. EarthVision Model of the Mattoon Sequestration Site

concern, since regionally, porosity may degrade significantly at depths below 8,000 feet. The two sites are located approximately 15 miles apart, and the proposed sequestration targets, well plan layout, and injection schemes are identical. Both sites use data from the same well (Weaber – Horn #1, about 36 miles from Mattoon) as the closest analog.

6.2 Mattoon Unknowns and Uncertainties

Reservoir uncertainties at Mattoon include depth, reservoir thickness, volume of effective porosity, and injectivity. The Mt. Simon was deposited on an eroded high-relief Precambrian surface, and thicknesses can change by hundreds of feet over small distances. Storage and capacity have moderate-to-high uncertainty. Porosity and permeability in the Mt. Simon are known to decrease with depth regionally, particularly at depths below 8,000 feet. The Mattoon site is 36 miles from the nearest well with subsurface data for the Mt. Simon. Interpretation of a single new 2-D seismic line acquired in fall 2006 has considerably reduced depth and thickness uncertainty. Advanced processing techniques may provide indirect evidence of the presence of porous intervals, although individual layers are likely to be too thin for seismic resolution. Uncertainty in porosity, permeability, and presence of transmissive faults may not be resolved prior to 3-D seismic acquisition following site selection. There is also some uncertainty related to the long-term resistance of the Eau Claire seal to permeation by CO_2. Regionally, the seal appears robust: the Eau Claire provides a seal for more than 30 natural gas storage reservoirs statewide. However, siltstone-shale mixed lithologies are typically not as impermeable as uniform shale lithologies. This is also suggested by core data from the Eau Claire seal at the Manlove natural gas storage facility, 54 miles north of the Mattoon site. This uncertainty can be reduced by core tests that would be conducted as part of subsurface characterization, if the Mattoon site were selected by the Alliance.

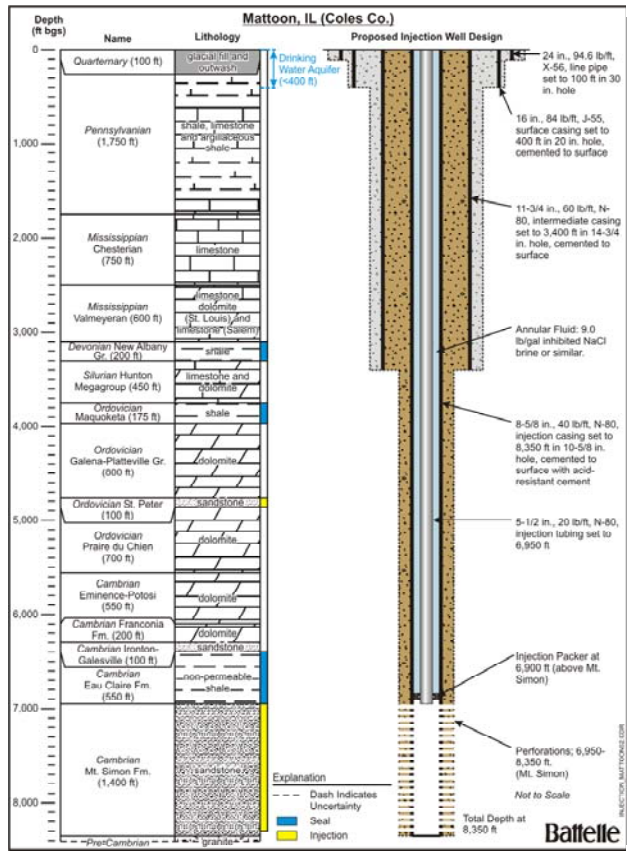


Figure 6.3. Mattoon Lithologies

Reservoir modeling indicates that a single well will provide sufficient capacity to meet the 2.5 MMT/yr injection rate described in the previous section. This analysis assumes that regional-scale outflow boundaries allow movement of the water displaced by the injected CO_2. If boundaries exist that restrict water outflow, additional wells will be required to distribute the CO_2 over a wider area or pressure relief wells (water extraction wells) may be required to control reservoir pressure. No known wells penetrate the Eau Claire seal; thus, no known wells intersect the largest modeled 50-year plume.

6.3 Tuscola

The Tuscola sequestration site (Figure 6.4) is located in a semi-rural area, approximately three miles south-southwest of the small town of Arcola in Douglas County, in east central Illinois. The site is 11 miles south of the proposed power plant, and three miles west of Interstate 57. The site is surrounded by mature and partially abandoned oil fields that produce from relatively shallow horizons (Figure 6.5).

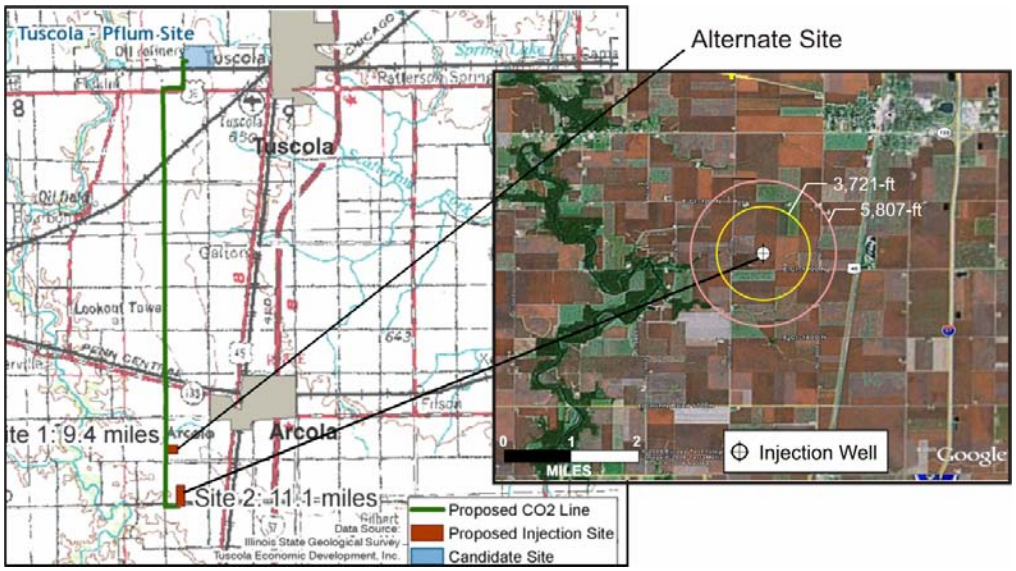


Figure 6.4. Location of the Tuscola Injection Site

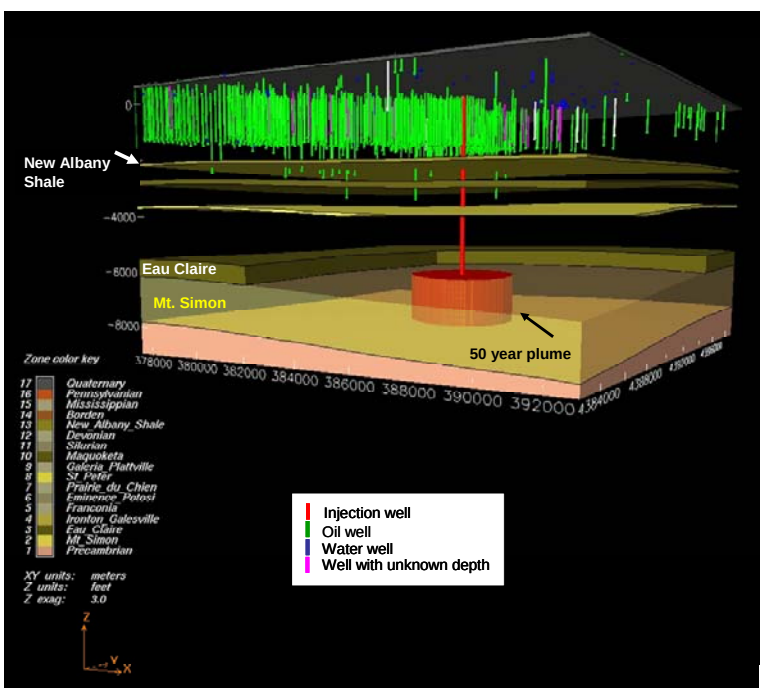


Figure 6.5. EarthVision model of the Tuscola Sequestration Site.

Within the largest modeled 50-year plume area, no known wells penetrate the Eau Claire formation, which is the primary seal, or the Maquoketa formation, which is the deepest secondary seal.

Figure 6.6 illustrates the Tuscola lithologies, including the seals (blue), and primary and optional injection zones (yellow). Also illustrated is the well design for the Tuscola injector and a back-up well. The primary injection zone is the thick, regionally important Mt. Simon saline formation. The St. Peter sandstone is successfully used as the target formation for gas storage facilities in areas of Illinois where the formation is closer to the surface.

Almost identical to the Mattoon Site approximately 15 miles to the south, the sequestration target for the Tuscola Site is the Mt. Simon sandstones, the regional seal is the Eau Claire, and the St Peter sandstone is submitted as an optional reservoir, requiring a separate well. Except for minor differences in depth and thickness, all reservoir properties submitted for the Tuscola site are identical to those for Mattoon.

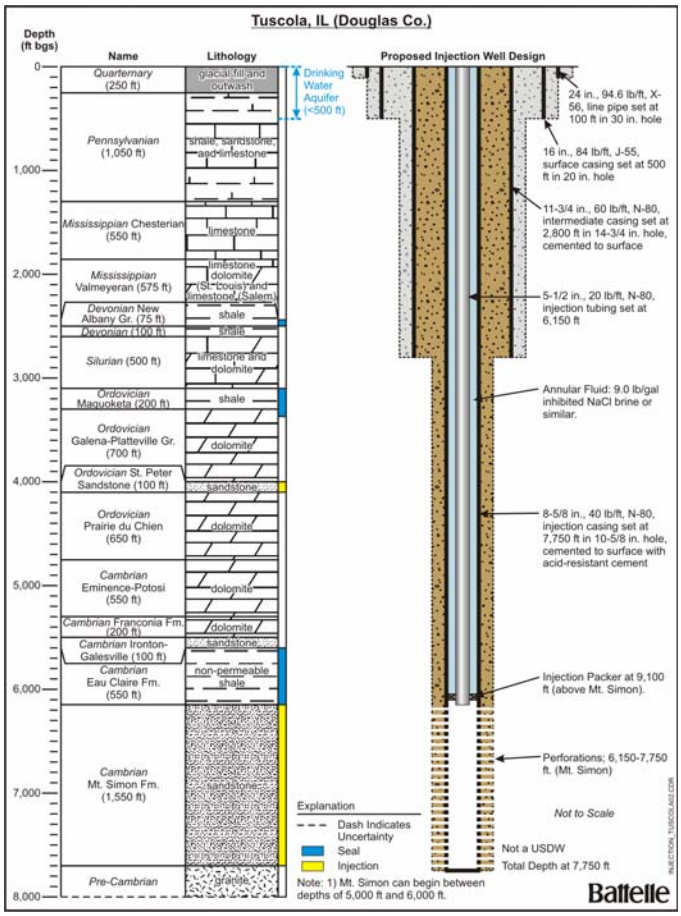


Figure 6.6. Tuscola Lithologies

The top of the Mt. Simon at the Tuscola Site is estimated to be between 5500 and 6250 feet. Thickness is estimated between 1500 and 1700 feet. The net effective porosity was estimated by the site offeror to be 600-675 feet. The base of the Mt. Simon at Tuscola is estimated to be at a depth of about 7750 feet, compared with about 8350 feet at Mattoon. The Tuscola injection well design (Figure 6.6) and perforation scheme are similar to that of Mattoon. Both sites use data from the same well (the Weaber-Horn #1) as the closest analog, although that well is about 56 miles from the Tuscola site. As numerically modeled, at least 50 MMT of CO_2 injected at a constant rate of 2.5 MMT per year for twenty years can be injected into a single well in the Mt. Simon formation at the Tuscola site. Across a range of modeled injection scenarios, the largest projected 20-year plume occurs in a scenario where 2.5 MMT is injected for twenty years. This 20-year plume size is approximately 998 acres[6], which corresponds to a plume radius of approximately 3721 feet (0.70 miles). After injection ends, this plume continues to expand. After 50 years, model results suggest it expands up to 1734 acres, which corresponds to a plume radius of approximately 4903 feet (0.93 miles). At an alternative injection rate of a constant 1 MMT/yr for 50 years, model results suggest that the 50-year plume will have a radius of 5807 feet (1.1 miles) and an area of 2432 acres. This is the largest 50-year plume across all modeled injection scenarios.

[6] The cited plume area includes 95% of the mass of the CO_2 plume.

Monitoring requirements follow the MM&V program detailed in Volume 2 of this document, but would be modified if previously unidentified wellbores or other hazards were discovered during pre-injection site characterization. Monitoring needs will be almost identical to those at Mattoon, except for a higher likelihood of abandoned or improperly plugged oil wells near the Tuscola site.

6.4 Tuscola Unknowns and Uncertainties

In addition to uncertainties that exist about the depth and thickness of the Mt. Simon, as at Mattoon there is considerable uncertainty associated with the relation between depth and porosity preservation. Regionally, effective porosity in the Mt. Simon appears to decrease with depth, and most of the analog data for the Illinois sites are from reservoirs shallower than that proposed for the injection sites. However, Battelle's numerical modeling supports the site offeror's capacity and injectivity calculations and indicates that at least 50 MMT of CO_2 can be injected, at a constant rate of 2.5 MMT per year for twenty years, even if the effective porosity is reduced to only one-third of that estimated by the site offeror.

Similar to the Mattoon case, reservoir modeling indicates that a single well will provide sufficient capacity to meet a 2.5 MMT/yr injection rate described in the previous section. This analysis assumes that regional-scale outflow boundaries allow movement of the water displaced by the injected CO_2. If boundaries exist that restrict water outflow, additional wells will be required to distribute the CO_2 over a wider area or pressure relief wells (water extraction wells) may be required to control reservoir pressure. Most of the uncertainties would be addressed during pre-injection reservoir characterization, and others would be expected to be resolved during drilling and testing of the first characterization well.

6.5 Odessa

The Odessa sequestration site (Figure 6.7) is located in a semi-arid, sparsely populated area adjacent to Interstate Highway 10 in Pecos County, Texas. The site is 58 miles south of the proposed power plant near Odessa Texas, three miles east of Fort Stockton, and about 60 miles south of the Midland-Odessa International Airport. The insert in Figure 6.7 shows the location of 10 injection wells, which are required to accommodate an injection rate of 2.5 MMT/year for 20 years or a peak injection rate of 6,850 tonnes/day. The red cross in Figure 6.7 shows the location of the power plant.

The proposed primary injection target consists of two intervals of fine-grained sandstones and siltstones with low to moderate porosity and permeability. The Delaware sandstones are at a depth of about 3600 feet and are between 1300 and 1800 feet thick. These sandstones are separated from the shallower Queen sandstones by about 450 feet of low permeability carbonates. The total combined effective porosity in both injection zones is about 130 feet. The closest analog well with porosity logs is within one mile of the most northern proposed injection well (Figure 6.8).

The top of the Queen injection interval is about 3000 feet. At the Odessa Site, CO_2 will become supercritical (temperatures greater than 31°C and pressure greater than 73 atmospheres) at depths greater than 2572 feet. Should the actual injection site or plume encounter a portion of the Queen at slightly shallower depth, the proximity of the reservoir conditions to the critical point could result in a phase transition to liquid and gas phase CO_2.

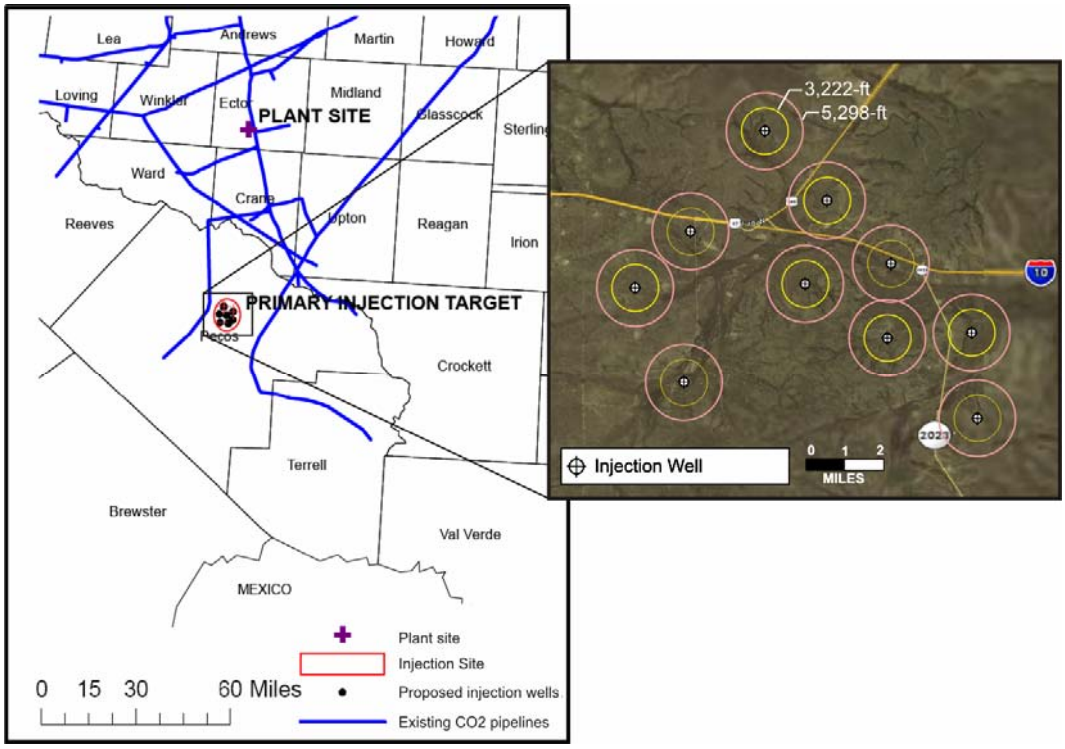


Figure 6.7. Location of the Odessa Injection Site

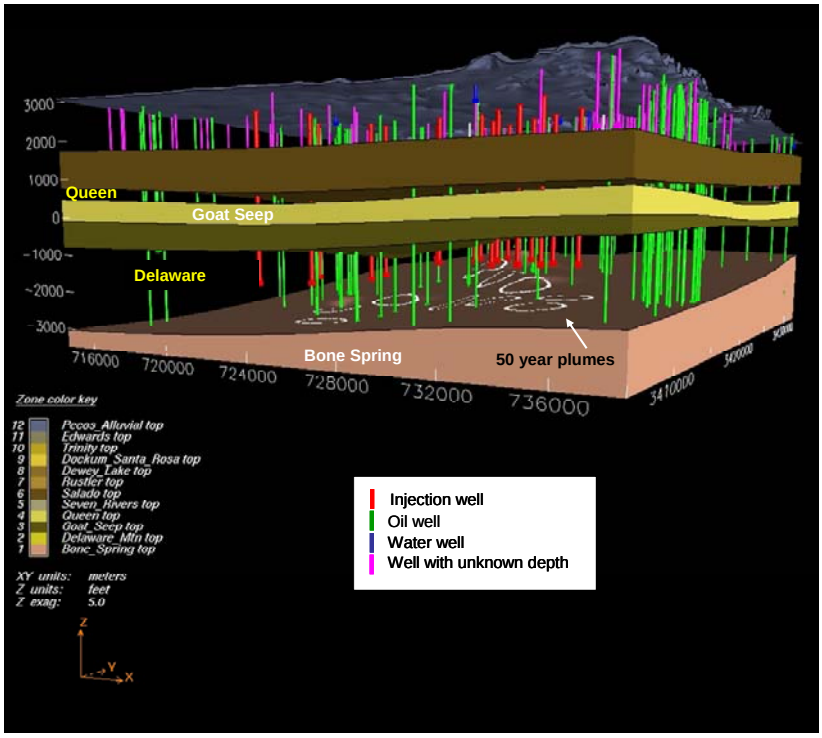


Figure 6.8. EarthVision Model of the Odessa Sequestration Site. The plumes shown are for the minimum required eight injection wells for the 2.5 MMT/yr constant injection rate at 50 yr. Vertical axis is in feet while horizontal axes are in meters.

Seven hundred feet of low permeability anhydrites and carbonates of the upper Queen and Seven Rivers form the regional primary seal above the lower Queen injection interval. The evaporites of the Salado Formation form a high quality, 500-foot thick secondary seal about 1000 feet above the Queen injection zone. There are existing wells that penetrate the Delaware sandstone interval; some of these have the potential to intersect with a 50-year CO_2 plume footprint, as presently configured. It is anticipated that because the site offeror controls a very large area for sequestration, it may be possible to place the injection wells to avoid these existing wells. The presence of any unidentified wells will present an additional hazard.

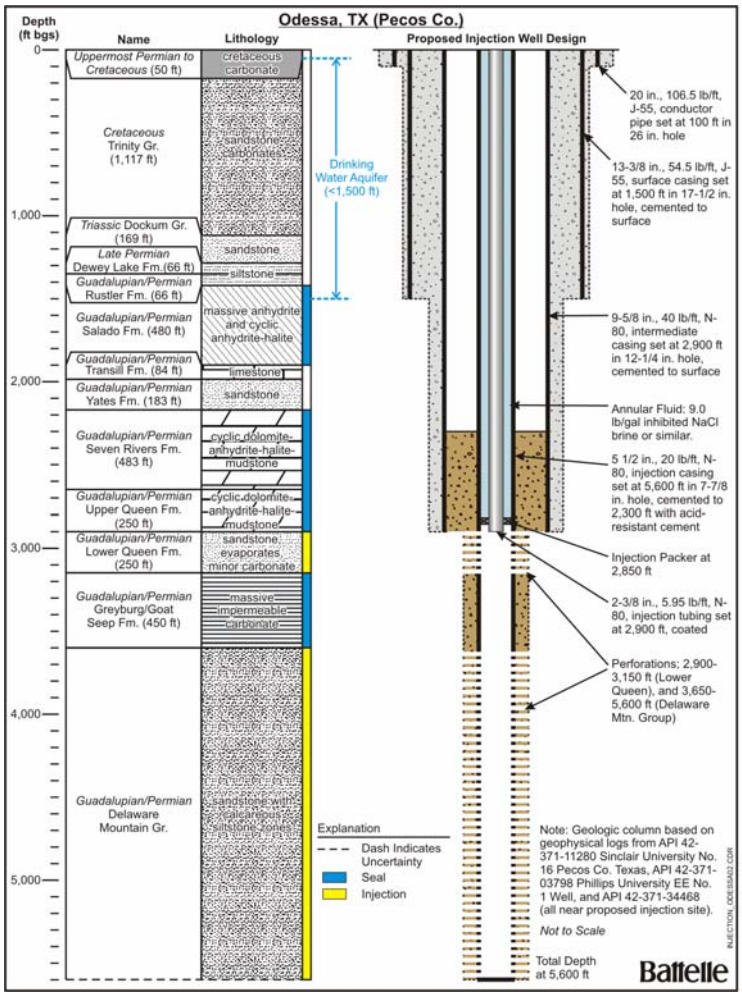


Figure 6.9. Odessa Lithologies

The injection scheme proposed for the Odessa Site consists of multiple vertical injection wells, with CO_2 injection over the entire thickness of the Delaware and Queen sandstones. The site is characterized by large storage capacity, but low permeability, as is typical of many saline reservoirs across the United States. The proposed injection well design and geologic profile are shown in Figure 6.9.

Numerical modeling by Battelle indicates that in order to inject a total of 50 MMT, a minimum of three wells are needed to accommodate 1 MMT/year of injection at a peak injection rate of 2,740 tonnes/day, and a minimum of eight wells are needed to accommodate an injection rate of 2.5 MMT/year (6,850 tonnes/day). The site offeror originally and more conservatively proposed 7 injection wells for the 1 MMT/yr case and 18 wells for the 2.5 MMT/yr case. No back-up wells are required. Injection rate in each well is limited by reservoir pressure constraints. While well spacing has been chosen to prevent CO_2 plume interference, the present calculations have not considered pressure wave interference among the multiple injection wells at the Odessa site. Consequently, costing and monitoring planning for the Odessa site have been evaluated assuming one additional well would be required for the 1 MMT/yr case (four total) and two additional wells would be required for the 2.5 MMT/yr case (10 total).

Examining a range of injection scenarios, the largest projected 20-year plume occurs in a scenario where 2.5 MMT is injected for twenty years (at 20 years, the size of the 1 MMT/yr plume is nearly identical but after 20 years is smaller than the 2.5 MMT/yr plume). This 20-year plume size is approximately

749 acres[7], which corresponds to a plume radius of approximately 3222 feet (0.61 miles). After injection ends, this plume continues to expand. After 50 years, model results suggest it expands up to 872 acres, which corresponds to a plume radius of approximately 3478 feet (0.66 miles). At an alternative injection rate of a constant 1 MMT/yr for 50 years, model results suggest that the 50-year plume will have a radius of 5298 feet (~1.00 mile) and an area of 2024 acres. This is the largest 50-year plume size across all modeled injection scenarios. However, after considering numbers of injection wells required, total plume area for the 1 MMT/yr case after 50yr is 6073 acres whereas total plume area after 50 yr is 6980 acres for the 2.5 MMT/yr case. Again, these acreage values represent the calculated plume area around one injection well multiplied by the minimum number of injection wells required to support the injection rate.

A conceptual design of an MM&V program is detailed in Volume 2 of this report. It would be refined if previously unidentified wellbores or other hazards were discovered during pre-injection. This site does require a larger area of monitoring than any of the other sites. The monitoring program at the Odessa site will include leakage potential of the existing wells that penetrate the Delaware sandstone interval.

6.6 Odessa Unknowns and Uncertainties

The Odessa site lithology (Figure 6.9) offers the opportunity to sequester CO_2 permanently as relatively small diameter cylinders in thick heterogeneous brine-filled sandstones. The general geology of the Odessa sequestration site is well known, due to hydrocarbon exploration activities, but local petrophysical and geomechanical seal and reservoir data are scarce. There are relatively low levels of uncertainty about the depth, thickness, and presence of the sequestration reservoirs. The conservative approach on reservoir parameters presented by the site offeror indicates that although reservoir porosity and permeability may turn out to be more favorable than estimated, they are not likely to be worse.

Numerical modeling supports the site offeror's calculations that multiple wells will be required to meet injectivity goals. The site offeror proposed seven injection wells to meet an injection rate of 1 MMT/yr and a total of 18 wells to meet the 2.5 MMT/yr injection requirements. The number of wells required to meet injectivity requirements is strongly dependent on assumptions regarding regional-scale outflow boundaries, analogous to the Illinois sites. The site offeror believes an overly conservation assumption was made in its original analysis of the Odessa site, where no-flow boundaries were imposed on the domain. Battelle's numerical modeling supports the site offeror calculations. This conservative assumption resulted in CO_2 storage being accommodated only through rock compressibility. Reconsideration of the appropriateness of the closed-system assumption resulted in a consensus view that outflow boundaries are likely at the Odessa site. An additional uncertainty involves pressure interference among the injection wells. Further analysis is needed to determine the extent of the interference. Several mitigation options are possible for the injection system design, including extended well spacing and installation of additional injection wells to minimize these effects. Most of the uncertainties would be addressed during pre-injection reservoir characterization, and others would be expected to be resolved during drilling and testing of the first characterization well.

[7] The cited plume area includes 95% of the mass of the CO_2 plume and corresponds to one well only.

6.7 Brazos, Texas

The Heart of Brazos sequestration site (Figure 6.10) is located in a semi-rural area about 65 miles north of the Bryan/College Station area in on two adjacent land parcels in Freestone County and Anderson County. The site is located 33 miles northeast of the proposed power plant, and 20 miles east of Interstate 45, about 60 miles east of Waco. The figure's inset shows new well layout of two Woodbine wells, and one Travis Peak well surrounded by four water production wells in a "five-spot" pattern. Circles indicate the largest 20- and 50-year plume footprints for each well at the total field injection rate of 2.5 MMT/year (with a peak injection rate of 6,850 tonnes/day).

Proposed injection is divided between the high porosity, high permeability 500-foot thick Woodbine sandstone that provides substantial capacity, and the heterogeneous 1800-foot thick Travis Peak sandstones that provide research opportunities on CO_2 fate and transport and on plume management (Figure 6.11). There are also two optional carbonate targets: the Rodessa and Pettet grainstones. All lie beneath an ultimate top seal, the Eagle Ford Shale, which has a thickness of 400 feet. The Woodbine sandstones are directly beneath the Eagle Ford seal. Travis Peak sandstones and Pettet limestones are sealed by the 80-foot thick Pine Island shale, and the Rodessa is sealed by Ferry Lake anhydrites and shales (Figure 6.12). The diverse lithologies of the saline formations have a wide variety of pore types and associated porosity/permeability relations, and offer a number of potential trapping mechanisms.

The top of the Woodbine is around 4800-feet. Porosity in the Woodbine generally ranges from 20–30%, with high permeabilities. The top of the Travis Peak is around 9,000 feet; and porosities at the injection site are expected to be generally between 4–8%, with low to moderate permeabilities. Permeability in the Travis Peak appears to be enhanced by pervasive, short length vertical fractures that increase permeability fivefold. There are sealing faults that cut, but do not completely offset, the 400-foot thick Eagle Ford seal at the northernmost injection wells. The Eagle Ford seal appears to have fairly high capillary entry pressure, as does the Ferry Lake seal.

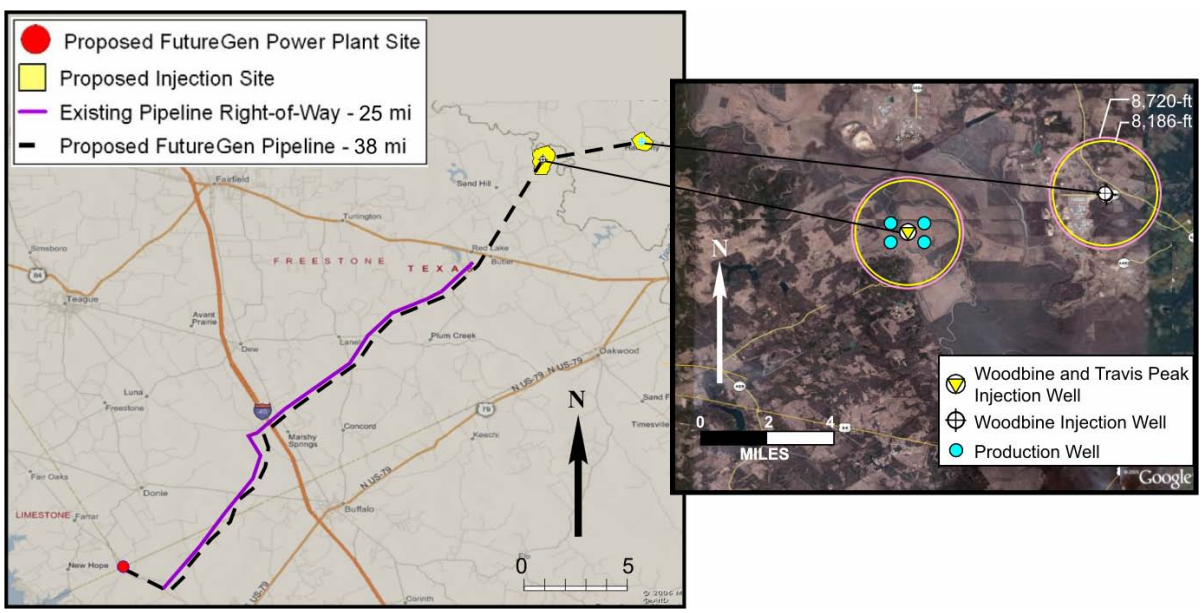


Figure 6.10. Location of the Proposed Brazos Sequestration Site

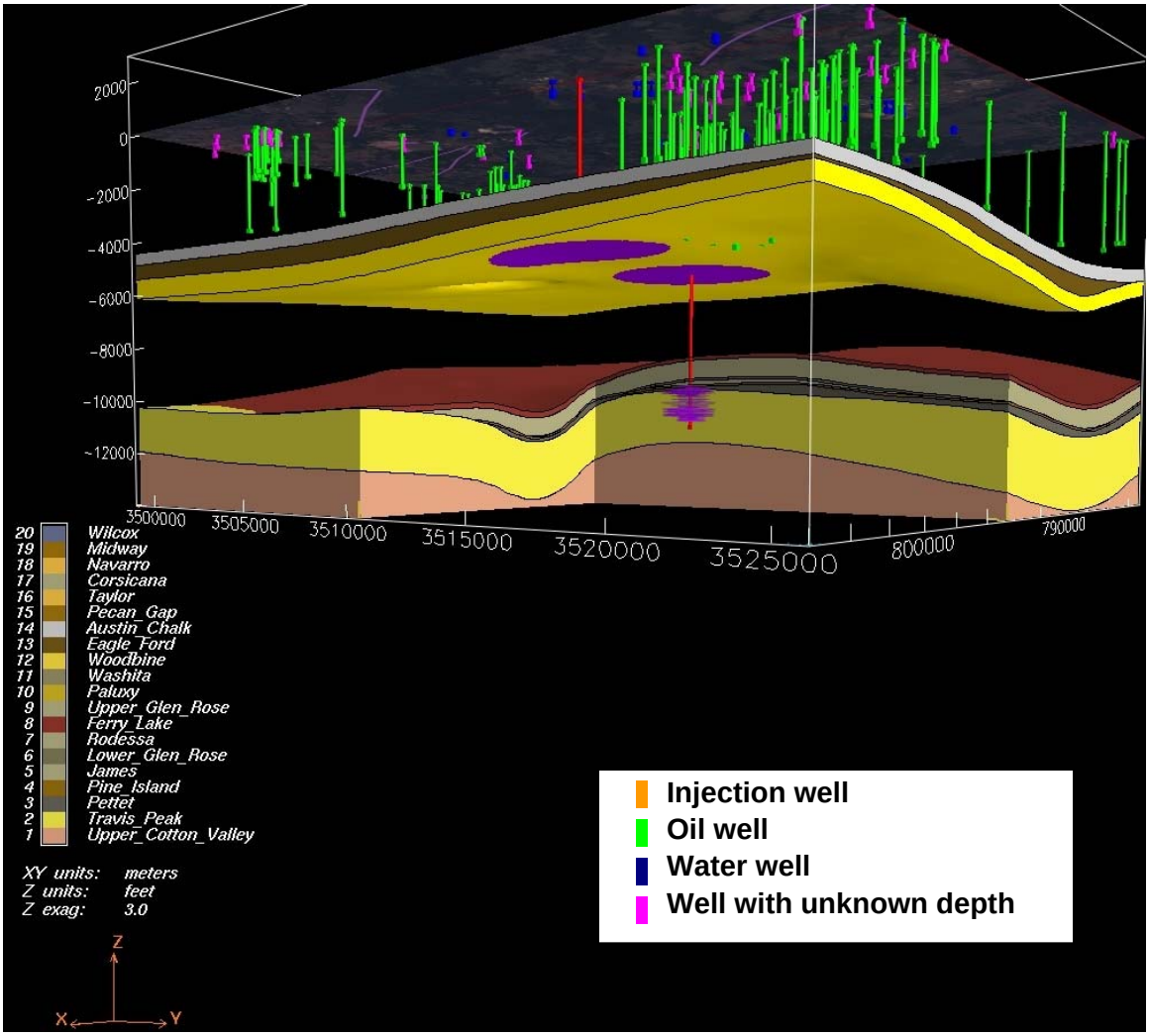


Figure 6.11. EarthVision Model of the Brazos Sequestration Site. The plumes shown are for the two injection wells into the Woodbine formation and one injection well into the Travis Peak formation. Vertical axis is in feet while horizontal axes are in meters.

As a basis for the design and cost estimates, the site was evaluated with two Woodbine injection wells, and one Travis Peak well that is surrounded by four water production (i.e., pressure management) wells. This configuration limits the spread of the CO_2 plume around the Woodbine injectors, and allows best accessibility to all intervals for testing and research. Only one Woodbine injection well is required to meet an injection rate of 1 MMT/year at a peak daily rate of 6850 tonnes/day and a total volume of 50 MMT. However, this volume (i.e., 50 MMT) would result in an extremely large plume footprint, which would extend beyond areas currently available for monitoring. Thus, multiple Woodbine injection wells were proposed by the site offeror. This results in a reduce plume footprint at each individual well. Travis Peak injection will be limited to 0.25 MMT/year with volumes above this rate injected into the Woodbine wells.

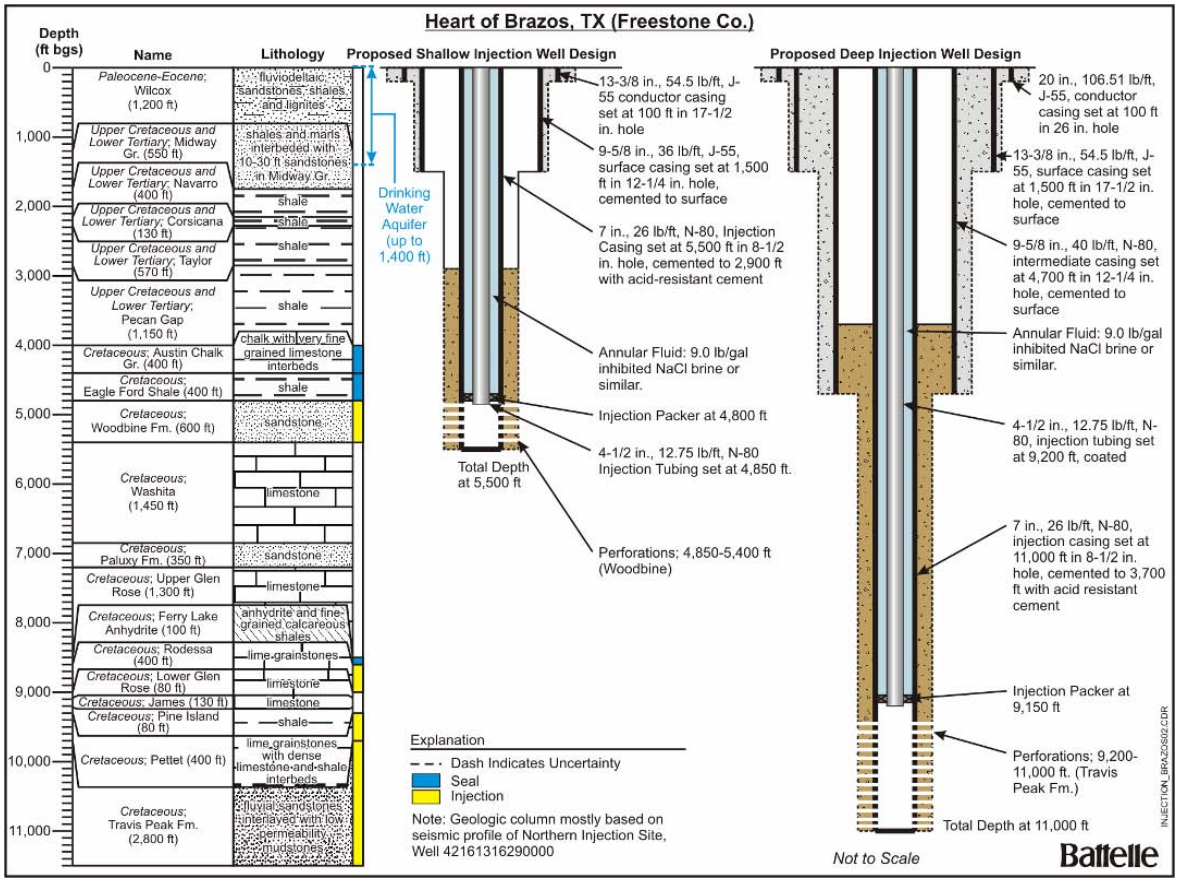


Figure 6.12. Brazos Lithologies

For the 2.5 MMT/year case just described (i.e., 1.125 MMT/year into each Woodbine well and 0.25 MMT/year into the single Travis Peak well), the largest projected plume area after 20-years of injection at this rate is approximately 4833 acres per Woodbine injection well[8], which corresponds to a plume radius of approximately 8186 feet (1.55 miles). The areal extent of the plume area for the Travis Peak well underlies and is within the areal extent of one of the Woodbine plumes. After injection ends, the Woodbine plumes continue to expand. After 50 years, model results suggest they expand up to 5484 acres per plume, which corresponds to a plume radius of approximately 8720 feet (1.65 miles). This is the largest 50-year plume across all modeled injection scenarios.

Numerous existing wells are located within the 50-year plume footprint of the two Woodbine wells, and a number of them penetrate the primary seal. A conceptual design for a monitoring program is detailed in Volume 2 of this report, and will includes a focus on detection of potential leakage from both well penetrations and faults.

[8] The cited plume area includes 95% of the mass of the CO_2 plume.

6.8 Brazos Unknowns and Uncertainties

The Brazos site offers the opportunity to sequester large volumes of CO_2 permanently, and to conduct a variety of experiments on plume management and long-term fate and transport experiments in a wide variety of lithologies and porosity systems, including thin fractured sandstones sandwiched between low permeability siltstones and shales. The subsurface geology of the sequestration site and of the general area is better known than at any of the other sites: 3-D seismic coverage exists over part of the area. Depth, thickness, and presence of the sequestration reservoirs have low uncertainties, as do the injectivity and capacity of the Woodbine sandstones. Actual plume size and shape are less certain, as the Woodbine sands are expected to follow paleo-shorelines. For this reason, the Woodbine wells have been well separated to avoid plume interference. We do not expect pressure wave interference between the two injection wells in the Woodbine to be a problem.

Injectivity and continuity of individual permeable sandstones in the Travis Peak have considerable uncertainty. The site offeror has presented a conservative approach to reservoir parameters in the Travis Peak, and although reservoir quality may differ from what has been estimated, it is more likely to improve than to degrade.

Most of the uncertainties associated with the subsurface would be addressed as a result of evaluation of 3-D seismic data acquired during pre-injection reservoir characterization; the other uncertainties are expected to be resolved during drilling and testing the first well.

7.0 CARBON DIOXIDE STORAGE

7.1 Preliminary Design Activity

This section covers FutureGen's preliminary subsurface design activity, including an examination of requirements for permanent CO_2 storage, identification of the basic elements of a large-scale CO_2 storage project, and development of best practices for monitoring, measuring, and verification (MM&V), including cost estimates. The section also outlines the role of third-party verification to assure stakeholders that CO_2 storage planning, oversight, and potential remediation are adequate.

7.1.1 Requirements for Permanent CO_2 Storage

The physical requirements for permanent CO_2 storage are storage capacity, seal integrity, and a plume that does not migrate away from the CO_2 storage site. The operational requirements for permanent CO_2 storage in saline formations include safe injection of CO_2 into an adequately-sized and reliable storage structure without adverse health, safety, or environmental effects.

Geologic seals and other low permeability layers are the main geologic structures that keep injected CO_2 from migrating to the ground surface. The greatest leakage hazard is compromise of the geologic seals through wellbore penetration, rupture, or permeation. An additional hazard exists when the CO_2 plume migrates out from under a competent seal or along pre-existing transmissive faults or fractures.

Operating a successful CO_2 storage project includes pre-drill and post-drill characterization of geologic seals—demonstrating that they are suitable for long-term storage and that during and after injection they are not compromised by dissolution, permeation, or CO_2 migration along boreholes or existing or induced fractures.

Hazards associated with leakage of CO_2 and accompanying brines from the reservoir include mobilization of metals and other contaminants in brines or as leachates from rock, displacement or contamination of drinking water by brines, lowering the pH of drinking water by CO_2, soil ecosystem impacts (vegetation, subterranean fauna), suffocation, and release of CO_2 back into the atmosphere.

Over time, sequestered CO_2 is expected to dissolve in the formation brines. Some of the dissolved CO_2 will react with fluid and rock chemistry to become part of the solid mineral matrix. Dissolved or mineralized CO_2 is no longer buoyant and will not rapidly migrate to the surface in the event of geologic seal failure.

7.1.2 Best Practices MM&V

Measuring, monitoring, and verification activities are standard elements of underground injection permitting and of reservoir management in hydrocarbon production, enhanced oil recovery, natural gas storage, and industrial waste disposal in deep geologic formations. Regulatory requirements and best practices from all these related fields have informed the process of determining the appropriate technologies and level of MM&V necessary for the Alliance to demonstrate that CO_2 storage has been successful.

The Offeror for each of the four candidate FutureGen sites has submitted a site-specific monitoring program in support of the NEPA process (Table 7.1). These monitoring approaches were compared

Table 7.1. Comparison of Proposed MM&V Approaches Against Other Injection Projects

Category	Method	Used at Other CO_2 Storage Sites					Proposed by Texas or Illinois
		Weyburn Canada	Frio TX	Lost Hills CA	Teapot Dome WY	Vacuum Field NM	
Remote Sensing	LIDAR	√					√
	INSAR			√			
	Hyperspectral Remote Sensing				√		
Atmospheric Monitoring	Eddy Covariance		√				√
Methods for Monitoring Processes at Surface and Near Surface	Soil Gas Sampling	√			√		√
	Surface Flux Emissions	√	√		√		√
	Vehicle Mounted CO_2 Leak Detection System						√
	CO_2 Wellhead Monitoring						√
	Borehole Tiltmeters				√		√
	Ecosystem Studies		√				
Methods For Monitoring Subsurface Phenomena	In-Situ P/T Monitoring	√	√	√	√	√	√
	Fluid Sampling	√	√	√			√
	Cross-well Seismic	√	√	√	√		√
	Wireline Tools	√	√	√			√
	Downhole Microseismic	√		√			
	3-D Time Lapsed Seismic	√	√	√	√	√	√
	2-D Time Lapsed Seismic						√
	Vertical Seismic Profiling	√	√		√		√
	Cross-well Resistivity		√	√	√	√	√
	LEERT						
	Permanent Seismic Sources/Receivers						
Off-Site Work	Database/GIS						√
	Workplan and Reporting						√

between sites, consolidated, and compared with regulatory approaches, standard approaches used by related industries, and approaches published by CO_2 storage experts. After careful review, a FutureGen approach was designed that has the greatest potential to meet FutureGen MM&V goals, be cost effective, and provide opportunities for research and development (R&D). This suite of monitoring techniques is compatible with the initial conceptual design and cost estimate. A final suite of monitoring techniques will be determined in subsequent project phases in consultation with independent experts.

7.1.3 Proposed FutureGen Approach for Successful CO_2 storage

The objectives of the best practice MM&V program are to:

- establish pre-injection/baseline conditions to compare with active injection and post-injection measurements;
- track location of CO_2 plume and phase distribution over time for validation of model predictions;

- detect leaks early, and quantify unexpected CO_2 seepage (for credits/emissions trading/liability reduction purposes, etc.);
- provide data to refine and calibrate reservoir models and other monitoring tools; and
- reassure public that protection of human health and the environment are high priorities of the Alliance.

The main components of monitoring are reservoir, caprock, drinking water sources, soil, and atmosphere. Establishing a well-defined baseline before start of injection provides a framework for interpreting changes in physical or chemical properties of any of these components. Baseline data also allow the first calibration of modeling results. Providing a linkage between model results and monitoring data is an important part of the MM&V design, and is necessary to ensure that the data needed for calibration and performance confirmation will be available.

A cost-effective monitoring program focuses on the largest risks. The monitoring program will be tailored to the specific conditions and risks at the selected storage site, depending upon the geologic setting, number of non-project wellbores, and nature of sensitive receptors. For a site with a stable well-defined caprock, the most likely pathways for leakage are injection wells or non-program wells that penetrate the primary seal. In this case, the monitoring program will focus on detecting leakage from injection, production (if any), and monitor wells, and on locating any active or abandoned wells in the area and ensuring they are not pathways to the land surface or to shallow aquifers. If the caprock is less well defined or has any indications of fracture zones or faults, the monitoring program will include a focus on tracking migration of the plume and ensuring that is does not leak through the caprock. The extent of land surface monitoring will depend on the local ecosystems and location of sensitive receptors. It is desirable that the monitoring program at all sites be designed to trigger and guide an intervention program in the case of off-normal events.

Table 7.2 presents a schedule for implementing one possible MM&V program, including monitoring infrastructure, atmosphere, near surface, and subsurface. This approach is further divided into baseline, injection, and post injection activities. This program will be reviewed by the Alliance and independent experts as part of the project's final design before adoption and implementation.

7.1.4 Role of Third Party Verification

Third party verification assures stakeholders that planning, oversight, and potential remediation are adequate to protect the public and the environment, and that the goal of carbon sequestration is being accomplished.

Verification of safety of the injection system begins with the state-required permitting process. Ultimately, regulatory oversight bodies will require periodic demonstration that the practice of geologic storage is safe, does not create significant adverse local environmental impacts, and that it is effective as a carbon management technology.

Because detailed description and verification of the FutureGen CO_2 storage process will inform the design of future projects and will provide data for a wide variety of third party analyses and R&D projects, the FutureGen MM&V program could include telemetry systems that continuously send sampled data from well-head and subsurface monitoring devices to centrally-located locations, where they undergo