SECTION 4 – ENGINEERING DESIGN AND OPERATING STRATEGY

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4.1 Introduction

The following section describes the engineering design details and operational strategies employed during the planning of the proposed White Castle Injection Well (WC IW-A) No. 001 carbon sequestration well. Along with WC IW-A No. 001, the engineering design details and operational strategies of the proposed stratigraphic, above-zone monitoring, and groundwater wells—respectively named White Castle Strat Well (WC SWMW) No. 001, White Castle Above-Zone Monitor Well (WC AZMW-A) No. 001, and White Castle Groundwater Well (WC GW-A) No. 001—are also presented in this section. The engineering design details meet the requirements of Statewide Order (SWO) 29-N-6 **§3621.A.1** [Title 40, U.S. Code of Federal Regulations (40 CFR) **§146.86**] Injection Well Operating Requirements and Injection Well Construction Requirements, respectively.

The design, construction, and operation of injection wells fall under the jurisdiction of the Environmental Protection Agency (EPA) Underground Injection Control (UIC) program. Since 1977, the UIC has governed the operation of injection wells, either at the federal level or through states that have been granted primacy over a certain type of well. In 2010, the EPA added an additional class of well, Class VI, which is specifically for the injection and storage of CO_2.

A significant amount of work has been conducted to evaluate various regions of the United States to assess the viability of carbon capture and sequestration (CCS) projects. Those evaluations focus on reservoir quality, proximity to emitters, and available pore space. The White Castle CO_2 Sequestration (White Castle) Project is an ideal CCS project for several reasons: (1) proximity to the New Orleans/Baton Rouge, Louisiana industrial region, where CO_2 emissions are estimated at approximately 80 million metric tons per year (MMT/yr); (2) the rural location of the large, contiguous pore space lease that is near existing third-party pipeline infrastructure slated for conversion to transportation of CO_2 emissions; and (3) optimal geological characteristics for storage and sequestration within the Miocene sands formation—including thick, high porosity, high permeability sands bedded with shale and mudstone, which will provide a cap and basement to multiple stacked injection intervals.

Class VI regulations include specific requirements for the design and operation of a CCS well. This section of the permit application addresses each of those requirements in detail.

4.2 Engineering Design

The design of the WC IW-A No. 001 is optimized to permanently sequester CO_2 gas, prevent its movement into Underground Sources of Drinking Water (USDWs), and account for various operational factors, such as injection volume, rate, chemical composition, and physical properties of the injectate fluid, as well as the corrosive nature of the injectate fluid and its impact on wellbore components. The operation of the well will be managed to ensure efficient use of pore space in the reservoir and contain the CO_2 within the authorized injection interval for the duration of the project.

The design of this well took into account several key considerations, including volume and rate of injection, chemical composition and physical properties of the injectate fluid, corrosion concerns, metallurgical evaluations, and operational details necessary to maintain proper reservoir management and well integrity.

Class VI wells are designed in a similar fashion as Class I injection wells, including specialized metallurgy to handle potentially corrosive fluids. CO_2 alone is not corrosive, but when combined with water and other chemical compounds, such as hydrogen sulfide (H_2S), it can create carbonic acid with a pH as low as 3. The injection wells are designed to withstand the corrosiveness of the injectate. Special metallurgies and coatings are considered for the casing, tubing, wellhead equipment, and downhole tools.

The drilling program also considers the types of cement that will be used in the wellbore. The cement design and products used to cement the well are designed to create good bonding between the casing and formations while withstanding the corrosive nature of the injectate. The cementing of the casings is designed with a sufficient cement sheath to protect the wellbore from developing any channeling out of the injection interval, and to maintain the CO_2 below the upper confining interval (UCI)—the approximately [redacted] formation known as the [redacted] that was discussed in detail in *Section 1.3.2*. Prior to approval to drill the proposed injection well, a detailed cement program will be finalized and provided for review. The cement program will include the type or grade of cement, cement additives including slurry weight (lb/gal) and yield (cu ft/sack), and other design details.

The WC IW-A No. 001 well will be located in the wooded wetlands in Iberville Parish, [redacted]. Existing pipelines near the Mississippi River corridor will be converted to transport emissions from regional industrial emitters to a central compression facility about [redacted] of the White Castle Project area. Compressed CO_2 will be transported from the central compression facility to WC IW-A No. 001 via a newly constructed pipeline for injection into the storage reservoir. Figure 4-2 (*Appendix A-3*) shows the proposed well location plat.

The Miocene sands, to be used as the storage reservoir for this project, are composed of stacked layers of sand and shale sequences (as discussed in *Section 1 – Site Characterization*). The Miocene sands in this area are generally located from 3,000' to 12,000' true vertical depth (TVD), and Harvest Bend CCS LLC (Harvest Bend CCS) plans to utilize WC IW-A No. 001 to inject and permanently sequester CO_2 in the [redacted] Due to their porous, permeable, and unconsolidated nature, the Miocene sands are an extremely desirable formation to be used for CO_2 injection and storage. WC IW-A No. 001 will be injecting into one continuous zone of sands through multiple recompletions over the life of the well. The design of the well accounts for this specific type of completion strategy.

The wellbore will be designed with [redacted] casing, with premium connections from the surface to [redacted]. There will be a [redacted] crossover at that point. The casing will be [redacted] from that crossover to total depth (TD). The [redacted] casing will be set [redacted] into the bottom-sealing formation. The production tubing will be [redacted], with premium connections and a [redacted] production packer. The packer should be located approximately [redacted] The packer location may change, provided there is at least [redacted] good cement bonding across the isolating shale directly above the top of the injection zone. The production packer will also be made of [redacted] material or a CO_2 injectate compatible material. In accordance with the metallurgical analysis provided in *Appendix E*, this design uses [redacted] material or its equivalent in all sections where the CO_2 will contact the tubulars. Final determination on the suitability of lesser chromium materials, such as [redacted], is still pending additional data gathering and testing. [redacted] Figure 4-1 (*Appendix D-1*) shows the wellbore schematic.

Annular and tubing pressures will be continuously monitored via downhole pressure gauges run on a fiber optic cable sensing package [redacted]. Pressures will be continuously monitored to ensure that well integrity is maintained. The fiber optic cable sensing package will include distributed acoustic sensing (DAS) and distributed temperature sensing (DTS) technology to support carbon front size monitoring through vertical seismic profile (VSP) surveys, if needed, and continuous temperature monitoring capabilities. A Supervisory Control and Data Acquisition (SCADA) monitoring system will be in place throughout the well's life.

Harvest Bend CCS also plans to drill a stratigraphic test ("strat") well [redacted] Upon drilling the test well, data will be gathered on the upper-confining, injection, and lower-confining intervals to better support the White Castle Project and to refine the carbon front modeling efforts, if needed. [redacted]

As part of the monitoring plan for WC IW-A No. 001, Harvest Bend CCS aims to drill one above-zone monitoring well and [redacted] dedicated USDW monitoring well [redacted]. The above-zone monitoring well on the WC IW-A No. 001 pad, WC AZMW-A No. 001, will be completed in the [redacted] sand—the first permeable zone above the [redacted]. The USDW monitoring well on the WC IW-A No. 001 pad, WC GW-A No. 001, will be drilled to the base of the USDW at around [redacted] near the proposed injection well.

[redacted]

Figure 4-1 – WC IW-A No. 001 Wellbore Schematic (Initial Completion)

[redacted]

Figure 4-2 – Well Location Plat - WC IW-A No. 001

4.2.1 General Outline of Well Design and Completion Schematic

WC IW-A No. 001 was designed with the following specifications:

- Drive Pipe
  - Size: [redacted]
  - Depth: [redacted]
- Surface Casing
  - To be set below the lowermost USDW
    - Currently estimated setting depth: [redacted]
      - Based on offset open-hole log evaluation
    - The USDW will be further confirmed via open-hole logging during the drilling of the well and adjusted as necessary.
  - Casing outside diameter (OD): [redacted]
  - Hole size: [redacted]
  - Top of cement: surface
- Intermediate Casing
  - [redacted] casing set at [redacted]
  - Composed of [redacted] grade
  - Hole size: [redacted]
  - Top of cement: surface
- Production Casing
  - [redacted] casing set at TD – [redacted]
    - [redacted] casing from surface to [redacted]
    - [redacted] casing below [redacted]
    - Crossover between [redacted]
    - [redacted] differential valve (DV) tools set:
      - [redacted]
  - Hole size: [redacted]
  - Top of cement: surface
    - Cement to be comprised of the following:
      - [redacted]
      - [redacted]
      - [redacted]
- Injection Tubing
  - [redacted] tubing set (initially) on packer, with tail pipe at [redacted]
  - Packer will be set [redacted].
  - Per metallurgical analysis, composition to be of [redacted]
  - Annular fluid to consist of corrosion inhibitor fluid
  - [redacted] at approximately [redacted]
  - Fiber optic cable (FOC) with DTS and DAS capabilities will be run [redacted].
    - Annular and tubing pressure gauges will be run on the end of the FOC [redacted].
- Packer (Figure 4-5, *Section 4.2.2.7*)

- [redacted] production packer
- Flow-wetted steel type: [redacted] or a CO_2 –injectate-compatible material
- Elastomer options: [redacted]
- Temperature range: [redacted]

- Wellhead (Figure 4-6, *Section 4.2.2.9*)
  - [redacted]
  - Production Tree
    - [redacted]

A complete drilling procedure has been included in *Appendix D-2*.

4.2.2 Detailed Discussion of Injection Well Design

The design of an injection well starts with the final tubing in mind and works backward. The required injection rate defines the tubing size, which defines the casing design and completion strategy.

Harvest Bend CCS plans to inject an average flow rate of 1.0 MMT/yr of gas into this proposed well, which translates to a daily injection rate of approximately 53 MMscf/d at standard conditions. Table 4-1 shows the standard conditions of CO_2 that are used in the modeling and flow calculations.

Table 4-1 – CO_2 Standard Conditions

CO_2 Standard Conditions				
Temperature (°F)	Pressure (psia**)	Density (lbm/cu ft)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm-°R)
77*	14.696	0.113	214.18	0.64759

*Basis of 25°C as per EPA standard conditions reference
**pounds per square inch absolute

An analysis was conducted on the tubing design by taking into account various factors, such as pipe friction losses, (erosional) velocities, thermal considerations, compression requirements, and economic evaluations. Using the results of the dynamic reservoir model, the bottomhole injection pressure (BHIP) was determined (Figure 4-3, page 11). The data obtained from this analysis is used to identify the point during the project's lifespan when the maximum BHIP occurs, as well as the resulting maximum flowing pressure at the surface. This information is used to properly design the casing, tubing, and wellhead configurations.

[redacted] During active operations, pressure will continuously be monitored to ensure BHP remains below 90% fracture gradient.

[redacted]

Figure 4-3 – Injection Pressure Plot

The pipeline specifications for the CO_2 stream to be injected in WC IW-A No. 001 are provided in Table 4-2. For conservative reservoir carbon front modeling purposes, the injectate was assumed to be 100% CO_2.

Table 4-2 – Injectate Composition Limits

Composition		Composition Amount	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		
[redacted]	[redacted]		
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	

A [redacted] tubing was determined to be the appropriate size necessary to move the desired volumes of supercritical CO_2 in this well, based on the model results. The model also verified that the CO_2 would remain in supercritical state in the wellbore. The CO_2 is in the supercritical state from the point it enters the wellhead—and remains supercritical throughout the path of the wellbore as it is being injected (Figure 4-4).

[redacted]

Figure 4-4 – CO_2 Flow Conditions

Based on appropriate bit-size selection, pipe clearance considerations, and recommended annular spacing for assurance of proper cementing, it was determined that the following casing sizes are appropriate to accommodate the [redacted] injection tubing.

- [redacted] drive pipe driven to [redacted]
- [redacted] open hole with [redacted] surface casing drilled to [redacted]
- [redacted] open hole with [redacted] intermediate casing drilled to [redacted]
- [redacted] open hole with [redacted] production casing drilled to [redacted]

4.2.2.1 Drive Pipe

Due to the loose and unconsolidated nature of the ground, a drive pipe will be required to maintain the integrity of the hole during the initial drilling of the well. A [redacted] drive pipe (Table 4-3) will be used for this purpose and will be driven using a casing hammer, either to the proposed depth or to refusal.

The selection of the drive-pipe size is based on the desired bit size for drilling the surface casing borehole. With a drive pipe inner diameter (ID) of [redacted], a [redacted] bit can be used to clean out the drive pipe and drill the next section of the well to a depth of [redacted].

After the drive pipe is in place, the inside of it can be flushed so the next stage of drilling can begin.

Table 4-3 – Drive Pipe Engineering Calculations

Drive Pipe								
Description	**Casing Wt. (ppf)**	**Depth (ft)**	**Tensile (psi)**	**Collapse (psi)**	**Burst (psi)**	**Capacity (bbl/ft)**	**ID (in.)**	**Drift ID (in.)**
[redacted]	[redacted]							
Safety Factor								

4.2.2.2 Surface Casing

The surface casing section of the well will be drilled using a [redacted] bit, which will create enough space to securely cement the [redacted] casing to the surface. The surface hole will be drilled with casing set at a minimum of [redacted] below the USDW, measured from ground level. This casing string, along with a proper cementing job, will provide two barriers to prevent contamination of the USDW during drilling operations. A cement-bond logging tool will be used to check the quality of the cementing job and ensure that it was successful.

Summaries of engineering calculations for the surface casing are provided in Table 4-4 (A, B, and C), including the cement calculations at Table 4-5 (A and B).

Table 4-4 – Surface Casing Engineering Calculations (A), Annular Geometry (B), and Casing (C)

(A) Surface Casing									
Description	Casing Wt.	Depth	Tensile	Collapse	Burst	Capacity	ID	Drift ID
	(ppf)	(ft)	(psi)	(psi)	(psi)	(bbl/ft)	(in.)	(in.)
[redacted]	[redacted]							
[redacted]								
Safety Factor								

(B) Annular Geometry			
Section	ID	MD	TVD
	(in)	(ft)	(ft)
Drive Pipe	[redacted]	[redacted]	[redacted]
Open Hole	[redacted]	[redacted]	[redacted]

(C) Casing					
Section	OD	ID	Weight	MD	TVD
	(in)	(in)	(lb/ft)	(ft)	(ft)
Surface	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 4-5 – Surface Casing Cement Calculations (A) Including Volume (B)

(A) Cement			
System	Top	Bottom	Volume of Cement
	(ft)	(ft)	(cf)
Lead	[redacted]	[redacted]	[redacted]
Tail	[redacted]	[redacted]	[redacted]

(B) Volume Calculations				
Section	Footage	capacity	% Excess	Cement Volume
	(ft)	(cf/ft)	(%)	(cf)
Drive Pipe/Casing Annulus Lead	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Lead	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Tail	[redacted]	[redacted]	[redacted]	[redacted]
Shoe Track Tail	[redacted]	[redacted]	[redacted]	[redacted]

To ensure cement returns to surface are achieved, excess of open-hole volumes will be pumped; 100% excess is assumed above but excess could be less based on the caliper log.

4.2.2.3 <u>Intermediate Casing</u>

For the intermediate casing section of the well, [redacted] casing has been selected. This section will be drilled with a [redacted] bit to provide sufficient annular space to cement the casing to surface with good bond. This casing string, along with an effective cement job, will provide two barriers to the USDW during drilling operations. After the surface and intermediate casing are set, there will be four barriers between the USDW and the fluid in the wellbore.

Summaries of engineering calculations for the intermediate casing are provided in Table 4-6 (A, B, and C), including the cement calculations at Table 4-7 (A and B).

Table 4-6 – Intermediate Casing Engineering Calculations

(A) Intermediate Casing								
Description	Casing Wt.	Depth	Tensile	Collapse	Burst	Capacity	ID	Drift ID
	(ppf)	(ft)	(psi)	(psi)	(psi)	(bbl/ft)	(in.)	(in.)
[redacted]	[redacted]							
Safety Factor								

(B) Annular Geometry			
Section	ID (in)	MD (ft)	TVD (ft)
Surface	[redacted]	[redacted]	[redacted]
Open Hole	[redacted]	[redacted]	[redacted]

(C) Casing					
Section	OD (in)	ID (in)	Weight (lb/ft)	MD (ft)	TVD (ft)
Intermediate	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 4-7 – Intermediate Casing Cement Calculations

(A) Cement			
System	Top (ft)	Bottom (ft)	Volume of Cement (cf)
Lead	[redacted]	[redacted]	[redacted]
Tail	[redacted]	[redacted]	[redacted]

(B) Volume Calculations				
Section	Footage (ft)	capacity (cf/ft)	% Excess (%)	Cement Volume (cf)
Surface Casing/Casing Annulus Lead	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Lead	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Tail	[redacted]	[redacted]	[redacted]	[redacted]
Shoe Track Tail	[redacted]	[redacted]	[redacted]	[redacted]

To ensure cement returns to surface are achieved, excess of open-hole volumes will be pumped; 30% excess is assumed above but excess could be less based on the caliper log.

4.2.2.4 Production Casing

Production casing (long-string casing) will run from the surface to TD and be cemented to surface. After the surface, intermediate, and production casings are set, there will be six barriers between the USDW and the fluid in the wellbore. Design criteria of production casing are the [redacted] material of the casing, [redacted] cement, and tools like centralizers, and float equipment.

A comprehensive metallurgical analysis, which considered the chemical composition of the CO_2 injectate and the downhole conditions, was conducted and is included in *Appendix E*. The analysis determined that the CO_2 injectate is not corrosive on its own. However, to protect against the potential for water from the reservoir entering the wellbore, and to guard against potential surface issues or failures, it was decided to use [redacted] for the downhole tubulars that will come into contact with the injectate stream.

[redacted] cement will be used to protect the cement sheath from degradation due to exposure to an acidic environment, thereby extending the well's integrity and lifespan. As Figure 4-1 showed (in *Section 4.2*), [redacted] cement will be placed to [redacted]. The entire cement column will be brought back to the surface using a [redacted] cement job.

Summaries of engineering calculations for the production casing are provided in Table 4-8 (A, B, and C), including the cement calculations at Table 4-9 (A and B).

Table 4-8 – Production Casing Engineering Calculations

(A) Production Casing								
Description	**Casing Wt.**	**Depth**	**Tensile**	**Collapse**	**Burst**	**Capacity**	**ID**	**Drift ID**
	(ppf)	**(ft)**	**(psi)**	**(psi)**	**(psi)**	**(bbl/ft)**	**(in.)**	**(in.)**
[redacted]	[redacted]							
[redacted]								
Safety Factor								
[redacted]								
[redacted]								
Safety Factor								

(B) Annular Geometry			
Section	**ID**	**MD**	**TVD**
	(in)	**(ft)**	**(ft)**
Intermediate Casing	[redacted]	[redacted]	[redacted]
Open Hole	[redacted]	[redacted]	[redacted]

(C) Casing					
Section	OD	ID	Weight	MD	TVD
	(in)	(in)	(lb/ft)	(ft)	(ft)
L-80	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
SM125CRW-125	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
DV Tool	[redacted]			[redacted]	[redacted]

Table 4-9 – Production Casing Cement Calculations

(A) Cement			
System	Top	Bottom	Volume of Cement
	(ft)	(ft)	(cf)
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

(B) Volume Calculations				
Section	Footage	Capacity	% Excess	Cement Volume
	(ft)	(cf/ft)	(%)	(cf)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Shoe Track	[redacted]	[redacted]	[redacted]	[redacted]

The production casing will be installed using premium connections. To ensure cement returns to surface are achieved, excess of open-hole volumes will be pumped; 30% excess is assumed above but excess could be less based on the caliper log.

4.2.2.5 Centralizers

Centralizer selection and installation for the referenced well will have two separate functions. The centralizer design for the [redacted] surface casing will be planned to protect any shallow aquifer zones per state regulations. The specific placement is also to ensure a continuous, uniform column of cement is present throughout the [redacted] annulus. The recommended location will be:

[redacted]

The centralizer design for the [redacted] intermediate casing will be planned per state regulations to ensure that a continuous, uniform column of cement is present throughout the [redacted] annulus. The recommended location will be:

[redacted]

[redacted]

The centralizer design for the [redacted] production casing will be planned per state regulations to ensure that a continuous, uniform column of cement is present throughout the [redacted] annulus. The recommended location will be:

[redacted]

Final centralizer design for all strings will be finalized at a later date when detailed cement design is also finalized and a stand-off model is completed.

4.2.2.6 <u>Injection Tubing</u>

As previously mentioned, the size of the injection tubing was chosen based on the injection volumes, rates, and injectate composition. It is important to consider the injectate and the potential for a corrosive environment when selecting the material of the tubing, similar to the casing string. The injectate stream is expected to be dry and non-corrosive, but the design allows for the possibility of a surface upset or the invasion of connate water from the reservoir. A comprehensive summary of the metallurgical analysis is included in *Appendix E*. Taking into account the potential for the presence of carbonic acid in a mixture of water and CO_2, tubing made of [redacted] material or better is recommended. Detailed injection tubing specifications are shown below in Table 4-10.

Table 4-10 – Injection Tubing Specifications

Tubing								
Description	Casing Wt. (ppf)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)
[redacted]	[redacted]							
Safety Factor								

The tubing will be installed using premium connections. FOC with DTS and DAS capabilities will be [redacted]. A cross-coupling cable protector will be mounted to each tubing joint coupling to protect the cable across couplings. Annular and tubing pressure gauges will be run on the end of the FOC [redacted].

4.2.2.7 Packer Discussion

The production tubing will be run into the well with a [redacted], production packer with premium connections (Figure 4-5).

[redacted]

Figure 4-5 – [redacted] Production Packer

The tubing and production casing annulus will be filled with a non-corrosive fluid as approved by the UIC Program Director (UIC Director), prior to setting the packer. Pressure will be maintained and monitored on the annulus at a pressure that exceeds the operating injection pressure of the well.

4.2.2.8 [redacted]

A [redacted] will be run at [redacted] that will enable a plug to be set via wireline in the [redacted] as a second barrier, to be able to work on any wellhead, surface leaks, or other surface problems safely.

[redacted]

4.2.2.9 Wellhead Discussion

The wellhead proposal, similar to the production packer, should be designed to combat working pressures and corrosion complications. The wellhead equipment will be manufactured with a combination of stainless-steel components across the hanger and casing spool, whereas Inconel lining will be located across trims, stems, gates, valves, etc. The wellhead is designed with a [redacted] working pressure rating and [redacted] for the flow-wetted components. Preliminary wellhead design is shown in Figure 4-6. Figure 4-7 shows a conceptual illustration of wellhead and injection skid valves and pressure and temperature monitoring equipment tied into a supervisory control and data acquisition (SCADA) system. Per SWO 29-N-6 **§3621.A.7.a.i** [40 CFR **§146.88(e)(2)]**, automatic shut-off systems and alarms will be installed to alert the operator and shut in the well when operating parameters such as annulus pressure, injection rate, etc., diverge from permitted ranges or gradients.

[redacted]

Figure 4-6 – Harvest Bend CCS WC IW-A No. 001 Preliminary Wellhead Design

[redacted]

Figure 4-7 – Typical Injection Well and Injection Skid Flow Schematic

4.2.3 Testing and Logging During Drilling and Completion Operations

A comprehensive subsurface data gathering (core, logging and fluids) and evaluation of the stratigraphic test well (WC SWMW No. 001) for the White Castle Project is planned in advance of the execution of the injection well. As described in *Section 4.3*, this planned data acquisition program not only satisfies SWO 29-N-6 **§3617.A** and **§3617.B** [40 CFR **§146.86** and **§146.87**], but also satisfies Harvest Bend CCS's internal best-practice criteria. The data acquired in the strat well will likely be analogous to that of the injection well and will be sufficient to adequately characterize the confining and injection intervals of interest. Additionally, if Harvest Bend CCS is unable to acquire any desired datasets from the strat well data gathering program, the injection well data gathering program will provide an opportunity to supplement the required information.

Harvest Bend CCS will implement similar *advanced* open-hole logging programs while drilling both the injection well and the strat well. Implementing the same logging programs in both the strat well and the injection well will allow for not only comprehensive comparison and demonstration of similar geology between the two wells, but also confidence in geological and carbon front models constructed from strat well data.

4.2.3.1 Coring Plan

As discussed in the drilling procedure in *Appendix D-2*, core samples will be collected during the drilling of the injection well in the UCI, the gross injection interval, and the lower confining interval.

Detailed evaluation of core and fluids can vastly improve the chances of successful CO_2 sequestration and result in overall cost savings. Uncertainty in intervals identified for CO_2 injection can be significantly reduced early on by investing in laboratory studies of confining and storage zone cores. Sections of whole core cut in [redacted] increments, with an option to lengthen core barrels to [redacted], will be collected from the [redacted] formation (upper confining interval) and the Miocene sands formation (injection interval) as listed in Table 4-11. Whole core will follow low-invasion acquisition protocol using high-performance, oil-based drilling fluid. Four-inch diameter whole cores will be obtained in the interval below the intermediate casing. Because of anticipated poor consolidation and lack of cohesion in these siliciclastic rocks, special vented-aluminum, disposable-core inner-barrels and full-closure core catchers will be utilized. Wellsite core handling, stabilization, and preservation will follow strict guidelines to ensure confining and injection interval cores remain representative of in situ rock properties.

If the sidewall coring tool for soft rock proves to be reliable, confining or injection intervals [redacted] will be supplemented with attempting up to [redacted] rotary sidewall cores (SWC). Wellsite core handling, stabilization, and preservation would be proportional to whole core footage and the number of sidewall cores acquired.

Given the supplemental nature of the core analysis in the injection well compared to the strat well core analytical programs (*Section 4.3.1*), analytical programs for confining and injection interval characterization will include:

[redacted]

The core analysis program has been designed to thoroughly confirm and supplement the characterization of confining and injection intervals through the strat well subsurface data gathering and evaluation programs discussed in *Section 4.3.1*. Additionally, the *advanced logs* discussed in Section *4.2.3.2*, for the injection well, will eliminate the need to collect whole core throughout the entire injection zone and confining system, which is more than 5,000' thick. The advanced logs will allow Harvest Bend CCS to extrapolate the results from select intervals in the coring plan throughout the entire gross interval.

Table 4-11 – Coring Program

Approximate Core Depth Intervals (ft TVDSS)	Core Type	Number of Cores	Predominate Lithology	Petition Interval
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Approximate Core Depth Intervals (ft TVDSS)	Core Type	Number of Cores	Predominate Lithology	Petition Interval
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

*SS – subsea

4.2.3.2 <u>Logging Plan</u>

A number of logging requirements are necessary to meet EPA standards and the needs of a responsible operation. These logging requirements can be described through the use of the three subsets detailed in Table 4-12. These are the *standard logs*, *advanced logs*, and *cased-hole logs*. *Standard logs* include the gamma ray, resistivity, neutron, density, caliper, and spontaneous potential. Spontaneous potential is only used in the zones with water-based mud. This data is used for primary reservoir and fluid characterization including lithology, porosity, salinity, fracture identification, indications of permeability, and fluid saturations. The *standard* logs can answer most of the primary reservoir questions related to storage volume.

Advanced logs, which make up the second set of tools, [redacted]

[redacted]

The planned *cased-hole logs* that will be run include radial cement bond logs as well as several other tools meant to set up baselines for the interval pre-injection. These baseline logs include casing inspection logs, imaging caliper, and [redacted]. Future logging of this zone with the same technology will allow the monitoring of the carbon front and the mechanical integrity of the wellbore.

Table 4-12 – Logging Plan

Wireline Logging Program		
Depth Interval	**Logs**	**Purpose/Comments**
Conductor Casing Interval ([redacted] feet below ground level (BGL))		
Casing (driven)	[redacted]	[redacted]
Surface Casing Interval		
Open-Hole Logs	[redacted]	[redacted]
	[redacted]	[redacted]
Casing Logs	[redacted]	[redacted]
Intermediate Casing Interval		
Open-Hole Logs	[redacted]	[redacted]
	[redacted]	[redacted]
Long-String Casing Interval		
Open-Hole Logs	[redacted]	[redacted]

Depth Interval	Logs	Purpose/Comments
Long-String Casing Interval (cont.)		
Open-Hole Logs (cont.)	[redacted]	[redacted]
Casing Logs	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]

4.2.3.3 Formation Fluid Testing

Prior to setting the production-casing string, samples of the formation fluid will be obtained by running an open-hole fluid recovery tool. Recovery sections will be determined based on open-hole evaluations. Multiple samples will be taken per section.

Brine chemistry by ICP spectrometry will be used to quantify major anions/cations. Formation fluid pH (including live water pH), total dissolved and suspended solids, conductivity, alkalinity, and specific gravity will be measured for basic brine characterization.

4.2.3.4 Minifrac Test

As discussed in *Section 5 – Testing and Monitoring Plan* and if required to further corroborate confining and injection interval characteristics determined through the strat well minifrac testing program discussed in *Section 4.3.1.4*, minifrac tests will be conducted during the open-hole logging program to measure the fracture gradient of the confining and injection intervals(s) in WC IW-A No. 001. This testing is in compliance with SWO 29-N-6 **§3617.B.4.a** [40 CFR **§146.87(d)(1)**] and SWO 29-N-6 **§3617.5.c** [40 CFR **§146.87€(3)**]. The tests will be conducted using a formation pressure and sampling tool.

Objectives

1. Achieve zonal isolation of the confining and injection intervals [redacted].
2. Perform injection and flowback test cycles to reduce the uncertainty and capture a better measure of the far-field minimum stress.
3. Measure tensile fracturing pressure, stress direction, far-field minimum and maximum stress, and tensile strength.

Regulatory Information

The Louisiana Department of Natural Resources (LDNR) regulates the injection wells in Louisiana. A Form UIC-17 must be submitted and all activities approved prior to commencing work. The minifrac test should also be witnessed by a Conservation Enforcement Specialist. A Form UIC-WH1 will be submitted to the LDNR Injection and Mining Division (IMD) at the conclusion of all tests, along with a report that includes an in-depth analysis of the minifrac tests.

4.2.3.5 Pressure Falloff Testing

Upon completion, but before operating the proposed injection well, Harvest Bend CCS will perform a required pressure falloff test per SWO 29-N-6 **§3617.B.5.a** [40 CFR **§146.87(e)(1)**]. The test will measure near-wellbore formation properties and monitor for near-wellbore environmental changes that may impact injectivity and result in pressure increases.

Testing Method

A non-hazardous fluid, approved by the LDNR, will be injected into the proposed well. The injection rate and pressure will be held as constant as possible prior to the beginning of the falloff test, and continuous data will be recorded during testing. Once the well has been shut in, continuous pressure measurements will be taken via a downhole gauge. The falloff period will end once the pressure-decay data plotted on a semi-log plot is a straight line, indicating radial flow conditions have been reached.

Analytical Methods

Near-wellbore conditions, such as the prevailing flow-regimes, well skin, and hydraulic property and boundary conditions, will be determined through standard diagnostic plotting. This determination is accomplished via analysis of observed pressure changes and/or pressure derivates on standard diagnostic log-log and semi-log plots. Significant changes in the well or reservoir conditions can be exposed by the comparison of pressure falloff tests prior to initial injection, with later tests. The effects of two-phase flow effects will also be considered. Such well parameters resulting from falloff testing will be compared against those used in AOR determination and site computational modeling. Notable changes in reservoir properties may dictate that an AOR reevaluation is necessary.

All pressure falloff test results will be submitted to the IMD within 30 days of test completion.

4.2.4 Injection Well Operating Strategy

Injection Interval (Gross): [redacted]
Maximum Injection Flow Rate: 1.5 MMT/year
Average Injection Flow Rate: 1 MMT/year
Maximum Surface Injection Pressure: [redacted]
Expected Surface Injection Pressure: [redacted]
Maximum Annular Pressure: [redacted]

Harvest Bend CCS currently plans on injecting an average of 1.0 MMT/year of CO_2 into WC IW-A No. 001, which will remain in the supercritical state within the reservoir during active injection. While closely monitoring pressures to ensure that bottomhole pressure does not exceed 90% of the fracture pressure of the injection reservoir or UCI (noted as Max BHP in Table 4-13), different circumstances could require an increased injection rate resulting in the accelerated development of a completion interval. For example, the White Castle Project includes multiple injection wells so that during well intervention events for other White Castle injection wells, Harvest Bend CCS will have the ability to increase the injection rate in WC IW-A No. 001 above the daily equivalent of 1.0 MMT/year, to continue to serve clients. Additionally, commercial requirements may result in increased injection rates up to 1.5 MMT/year and accelerated development of completion intervals. If injection rates persist above the planned average of 1.0 MMT/year, it is expected that the injection durations listed in Table 4-13 will decrease so that the total storage volume of each completion interval is not exceeded. Again, despite possible increases in injection rate above 1.0 MMT/year, pressures will be closely monitored to ensure that bottomhole pressure does not exceed 90% of the fracture pressure of the injection reservoir or UCI.

During active injection operations, the average bottomhole pressure increase expected will be [redacted] but this increase will drop to [redacted] psi post-injection. The Miocene sand reservoir properties allow for the dissipation of the pressure quickly. Expected surface and bottomhole pressure considerations are detailed for each completion stage in Table 4-13.

Bottomhole pressure does not exceed 90% of the fracture pressure of the injection reservoir or UCI, which will limit surface injection pressure. The anticipated BHIP, fracture gradient with 10% safety factor, and injection rate plot over time is shown in Table 4-13.

Table 4-13 – Injection Pressure by Stage

Completion Stage	Injection Duration (yrs)	Total Storage Volume (MMT)	Max Rate (MMT/yr)	Average Rate (MMT/yr)	Max BHP (psi)	Average BHP (psi)	Max WHP (psi)	Average WHP (psi)
[redacted]								

Multiple injection intervals are used to maximize the use of available pore space. This is the optimal way to inject, because if all intervals were perforated at once, the gas would not be evenly distributed throughout the reservoir. There will be discrete injection intervals utilized for a given amount of time and then abandoned (Table 4-14).

Table 4-14 – Injection Intervals

Completion Stage	Injection Duration (years)	Top Perf (TVD ft)	Bottom Perf (TVD ft)	Net Pay (ft)
[redacted]				

The density of the injectate typically ranges from [redacted] in the shallowest injection interval to [redacted] in the deepest injection interval, compared to [redacted] for the connate brine in the same formations. This density difference, coupled with the high vertical permeability in the Miocene sands, allows the CO_2 to migrate upward to the top of each discrete injection interval, and laterally under the confining layer of that interval.

This results in a significant "mushroom cap" effect seen in Figure 4-8 below.

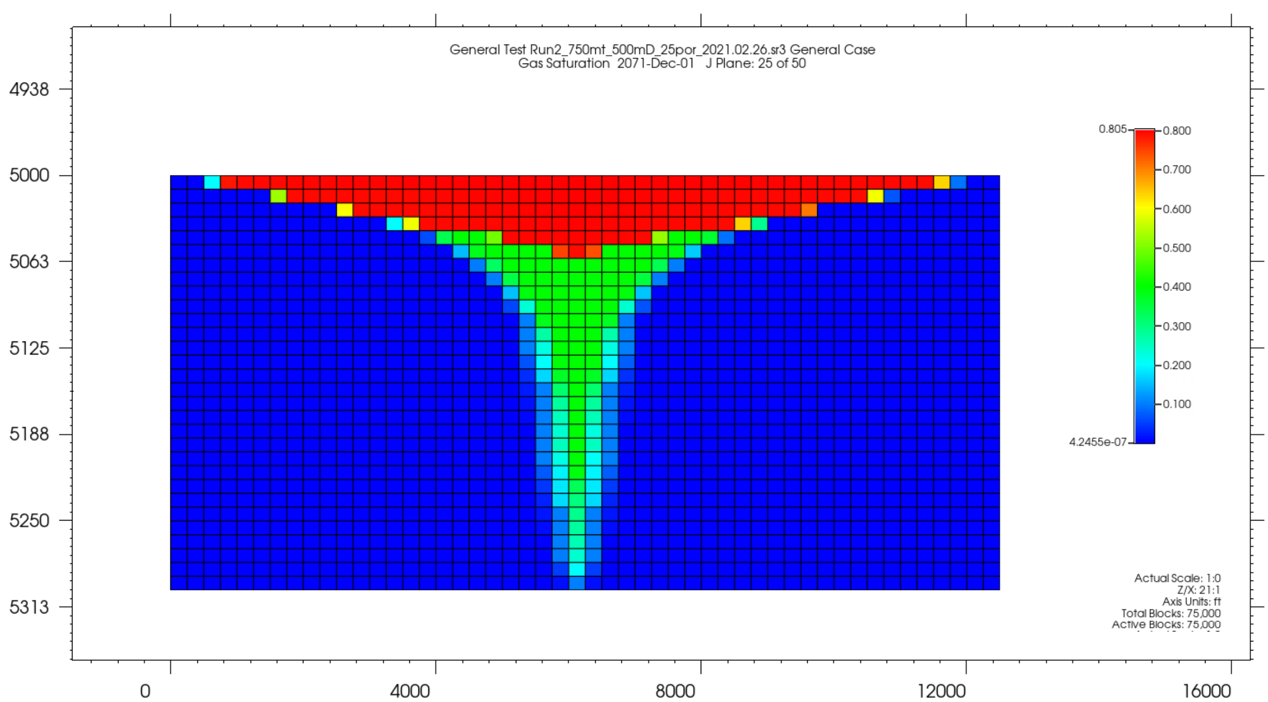

Figure 4-8 – Typical Carbon Front Profile in Loose Formations

To make the most use of the pore space, specific intervals for injecting CO_2 need to be determined. This can be done by creating a detailed geological model, modeling the injection of CO_2 in the reservoir, and building a carbon front model based on the specific well completion strategy. From this strategy, maps of the carbon and pressure fronts will be generated to show the lateral extent of the carbon front. These maps will then be used to confirm which areas of the pore space will be affected by the carbon front.

Reservoir management is extremely important for disposal wells. The operating strategy for WC IW-A No. 001 is as follows:

- The gross injection interval will be broken into several "discrete injection intervals."
- These injection intervals are then divided into discrete completion intervals.
- The discrete intervals are perforated.
- The injectate fluids are injected into the discrete completions for a relatively short period of time—no less than 1 year; no more than 5 years (estimated).
- Pressure transient analysis to be conducted each year to contrast actual carbon front development with the simulated carbon front model.
- As determined by seismic surveying and dynamic modeling efforts, once a completion interval has been fully developed, the interval is isolated and a recompletion to the next interval is performed.
- The completed sub-section is then plugged with a corrosion-resistant plug.
- This process repeats until the entirety of the gross injection interval has been completed.

Figure 4-9 depicts this process in a general form.

[redacted]

Figure 4-9 – Operational Completion Strategy

The actual injection intervals, time frame, and rate can be found in Tables 4-13 and 4-14.

The sand packages to be targeted by the completion intervals identified in Table 4-14 were selected by analysis of the static model at the proposed injection location that was populated from offset well data and seismic attributes. The actual discrete intervals completed and final staging will be selected based on well-specific data.

4.2.5 Injection Well Operational Strategy Summary

WC IW-A No. 001 is engineered to optimize the utilization of pore space and securely store CO_2 in the most secure, least hazardous, efficient, and cost-effective manner feasible. The pressure and temperature within the wellbore will be determined, and these measurements will be incorporated into the carbon front model and the strategies for future injections will be refined, as outlined in the Testing and Monitoring Plan (*Section 5*). This will help ensure that the movement and rate of the CO_2 is accurately assessed and, if necessary, adjustments can be made to the injection and operational plans. Once injection has stopped, the well will be sealed as per the Injection Well Plugging Plan (*Section 6*).

To confirm that the carbon front is developing as expected, a time-lapse seismic carbon front monitoring approach will be utilized as outlined in the Test and Monitoring Plan (*Section 5*).

Carbon front growth will be monitored with time-lapse seismic surveys. [redacted] Any variations observed between the surveys and the carbon front model will be used to further improve the completion strategy. This iterative process will ensure that the movement and rate of the CO_2 is accurately evaluated and, if necessary, adjustments can be made to the completion and operational plans. Once all of the available sand packages have been utilized, the well will be sealed.

As previously mentioned, the location of this project is ideal for carbon sequestration. By combining the best engineering practices in well design with both a cutting-edge monitoring system and a comprehensive reservoir management strategy, this well will safely and permanently store CO_2.

4.3 <u>Stratigraphic Test Well</u>

Harvest Bend CCS intends to drill a strat well named WC SWMW No. 001 to extensively gather and evaluate subsurface data for the confining and injection intervals. Following data gathering exercises, WC SWMW No. 001 will be cased, but not completed like the injection well and above-zone monitoring well. [redacted]

The location and design of the strat well have not yet been finalized. It is anticipated that the strat well will be drilled [redacted]. Once location and design are finalized, the well will be permitted with LDNR as a Class V well. Design can be further reviewed and approved at that time through the Class V well application process.

4.3.1 Testing and Logging of Strat Well During Drilling and Completion Operations

A comprehensive subsurface data gathering (core, logging and fluids) and evaluation of the strat test well is planned in advance of the execution of the injection well. As described below, the planned data acquisition program not only satisfies SWO 29-N-6 **§3617.A** and **§3617.B** [40 CFR **§146.86** and **§146.87**], but also satisfies Harvest Bend CCS's internal best-practice criteria. Data gathered during testing and logging programs will be used to further characterize the proposed injection interval and confining layers for WC IW-A No. 001. The analytical results from the detailed evaluation programs will be used to validate current reservoir modeling assumptions and update the model (*Section 2 – Carbon Front Model*) and this Class VI application as needed.

4.3.1.1 <u>Coring Plan</u>

Detailed evaluation of core and fluids can vastly improve the chances of successful CO_2 sequestration and can result in overall cost savings and, potentially, determination of additional storage capacity. Uncertainty in intervals identified for CO_2 injection can be significantly reduced early on by investing in laboratory studies of confining seal and injection interval cores. Sections of whole core cut in [redacted] increments, with an option to lengthen core barrels to [redacted], will be collected from the [redacted] formation (upper confining interval) and the Miocene sands formation (injection interval) as listed in Table 4-15. Whole core will follow low-invasion acquisition protocol using high-performance, oil-based drilling fluid. Four-inch diameter whole cores will be obtained in the interval below the intermediate casing. Because of anticipated poor consolidation and lack of cohesion in these siliciclastic rocks, special vented-aluminum, disposable-core inner-barrels and full-closure core catchers will be utilized. Wellsite core handling, stabilization, and preservation will follow strict guidelines to ensure confining and injection interval cores remain representative of in situ rock properties. Sidewall cores will be acquired to fill gaps between whole core depths.

Detailed analytical programs will be conducted for seal and injection zone characterization to include:

[redacted]

The core analysis program has been designed to thoroughly confirm and supplement the characterization of confining and injection intervals through the strat well subsurface data gathering and evaluation programs.

Table 4-15 – Coring Program

Approximate Core Depth Intervals (ft TVDSS)	Core Type	Predominate Lithology	Petition Interval

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

4.3.1.2 Logging Plan

Open-hole log data will be acquired reflecting in situ, structural, stratigraphic, physical, chemical, and geomechanical information for the Miocene sands formation, the [redacted] confining intervals, and other zones of interest. Wireline-conveyed open-hole logs will be acquired at the surface casing point, intermediate casing point, and over the production zone—including the injection targets. Open-hole logs will not be acquired in the conductor casing hole.

While drilling the strat well, Harvest Bend CCS will implement a similar logging program as is planned in the injection well and discussed in detail in *Section 4.2.3*. Implementing the same robust open-hole logging programs in both the strat well and the injection well will allow for comprehensive comparison and demonstration of similar geology between the two wells and confidence in geological and carbon front models constructed from strat well data.

4.3.1.3 Formation Fluid Testing

Prior to setting the production casing string, samples of the formation fluid will be obtained by running an open-hole fluid recovery tool. Recovery sections will be determined based on open-hole evaluations. Multiple samples will be taken per section.

Understanding the thermo-physical properties of supercritical CO_2 ($scCO_2$) and formation brine are critical for achieving safe and long-term storage of $scCO_2$. Brine chemistry by inductively coupled plasma (ICP) spectrometry for quantifying major anions/cations along with pH (including live water pH measurement), total dissolved and suspended solids, conductivity, alkalinity, and specific gravity are essential for basic brine characterization.

Fluid chemistry controls the amount of CO_2 that can dissolve in the brine (solubility), affecting estimates of carbon dioxide trapping and storage capacity. Solubility of $scCO_2$ in brine must be high for efficient trapping and this variable will be quantified. The in situ dissolution of $scCO_2$ depends on the pressure, temperature, and salinity of the formation brine.

[redacted] Capillary pressure in the seal that includes $scCO_2$-brine IFT must be higher than the buoyancy forces exerted by the seal to prevent upward migration and escape of CO_2. Interfacial tension effects can also influence effective permeabilities and $scCO_2$-formation brine relative permeabilities.

[redacted] The viscosity contrast between $scCO_2$ and $scCO_2$-saturated brine must be sufficiently high to prevent the displacement of stored CO_2 by brine; these viscosities will be measured with a capillary viscometer. Brine compressibility by Constant Composition Expansion will be determined for quantifying CO_2 and storage capacity, as well as the change in aquifer volume with changing pressure.

4.3.1.4 Minifrac Test

As discussed in *Section 5 – Testing and Monitoring Plan*, during the open-hole logging program, minifrac tests will be conducted to measure the fracture gradient of the confining and injection intervals(s) in WC SWMW No. 001. This testing relates to the injection well requirements in SWO 29-N-6 **§3617.B.4.a** [40 CFR **§146.87(d)(1)**] and SWO 29-N-6 **§3617.5.c** [40 CFR **§146.87€(3)**] and is meant to supplement and possibly fulfill these data gathering requirements for the storage reservoir. The tests will be conducted using a formation pressure and sampling tool.

Objectives

1. Achieve zonal isolation of the confining and injection intervals [redacted].
2. Perform several (up to four or five) injection and flowback test cycles to reduce the uncertainty and capture a better measure of the far-field minimum stress.
3. Measure tensile fracturing pressure, stress direction, far-field minimum and maximum stress, and tensile strength.

4.3.2 Overview of Stratigraphic Well Completion Program

[redacted]

4.3.3 Stratigraphic Well Operational Strategy Summary

WC SWMW No. 001 is engineered to be an available test well, if needed, for the purpose of gathering subsurface data for WC IW-A No. 001 prior to injection. WC SWMW No. 001 will be located [redacted] The primary purpose of the strat well is to gather reservoir data, such as whole cores, fluid samples, and open-hole logs, from the Miocene sands formation and confining layers. [redacted]

4.4 Above-Zone Monitoring Well

Harvest Bend CCS intends to drill and complete an above-zone monitoring well [redacted] WC AZMW-A No. 001, [redacted], will monitor the first permeable zone above the UCI—the [redacted] formation—with the same pressure and temperature sensor technology used in the injection well. Tubing pressures will be monitored via downhole pressure gauges run on a fiber optic cable sensing package [redacted]. WC AZMW-A No. 001 will be situated in the currently predicted carbon and critical-pressure boundaries and will monitor for signs of CO_2 escaping through the UCI. This well will not be drilled through the UCI, thus it will not require acid-resistant materials for its construction.

The proposed preliminary design for WC AZMW-A No. 001 is depicted in Figure 4-10 (*Appendix D-3*).

[redacted]

Figure 4-10 – WC AZMW-A No. 001 Wellbore Schematic

4.4.1 General Outline of Well Design and Completion Schematic

WC AZMW-A No. 001 was designed with the following specifications:

- Drive Pipe
  - Size: [redacted]
  - Depth: [redacted]
- Surface Casing
  - To be set below the lowermost USDW
    - Currently estimated setting depth: [redacted]
      - Based on offset open-hole log evaluation
    - The USDW will be further confirmed via open-hole logging during the drilling of the well and adjusted as necessary.
  - Casing OD: [redacted]
  - Top of cement: surface
- Production Casing
  - [redacted] casing set at TD – [redacted]
  - Composed of [redacted] grade
  - Hole size: [redacted]
  - Top of cement: surface
- Injection Tubing
  - [redacted] tubing set on packer, with tail pipe at [redacted]
  - Per metallurgical analysis, composition to be of [redacted]
  - Annular fluid to consist of corrosion-inhibitor fluid
  - [redacted] at approximately [redacted]
  - Fiber-optic cable (FOC) will be run [redacted].
    - Tubing pressure and temperature gauges will be run on the end of the FOC [redacted].
- Packer (Figure 4-11, *Section 4.4.2.6*)
  - [redacted] production packer
  - Elastomer options: [redacted]
  - Temperature rating: [redacted]
- Wellhead (Figure 4-12, *Section 4.4.2.7*)
  - [redacted]
  - Production Tree
    - [redacted]

4.4.2 Detailed Discussion of Above-Zone Well Design

Based on appropriate bit-size selection, pipe-clearance considerations, and recommended annular spacing for assurance of proper cementing, it was determined that the following casing sizes are appropriate to accommodate the [redacted] injection tubing:

- [redacted] drive pipe driven to [redacted]
- [redacted] open hole with [redacted] surface casing drilled to [redacted]
- [redacted] open hole with [redacted] production casing drilled to [redacted]

4.4.2.1 Drive Pipe

Due to the loose and unconsolidated nature of the sediments found below the waterline, a drive pipe will be required to maintain the integrity of the hole during the initial drilling of the well. A [redacted] drive pipe will be used for this purpose. The pipe will be driven using a casing hammer, either to the proposed depth or to refusal.

The selection of the drive pipe size (Table 4-16) is based on the desired bit size for drilling the surface casing borehole. With a drive pipe having an ID of [redacted], a [redacted] bit can be used to clean out the drive pipe and drill the next section of the well to a depth of [redacted].

After the drive pipe is in place, the inside of the pipe can be flushed, allowing the next stage of drilling to begin.

Table 4-16 – Drive Pipe Engineering Calculations

Drive Pipe								
Description	**Casing Wt.**	**Depth**	**Tensile**	**Collapse**	**Burst**	**Capacity**	**ID**	**Drift ID**
	(ppf)	**(ft)**	**(psi)**	**(psi)**	**(psi)**	**(bbl/ft)**	**(in.)**	**(in.)**
[redacted]	[redacted]							
[redacted]	[redacted]							
Safety Factor	[redacted]							

4.4.2.2 Surface Casing

The surface casing section of the well will be drilled using an [redacted] bit, which will create enough space to securely cement the [redacted] casing to the surface. The surface hole will be drilled with casing set at a minimum of [redacted] below the USDW, measured from ground level. This casing string, along with a proper cementing job, will provide two barriers to prevent contamination of the USDW during drilling operations. A cement-bond logging tool will be used to check the quality of the cementing job, to ensure that it was successful.

Summaries of engineering calculations for the surface casing are provided in Table 4-17 (A, B, and C), including the cement calculations at Table 4-18 (A and B).

Table 4-17 – Surface Casing Engineering Calculations

(A) Surface Casing								
Description	**Casing Wt.**	**Depth**	**Tensile**	**Collapse**	**Burst**	**Capacity**	**ID**	**Drift ID**
	(ppf)	**(ft)**	**(psi)**	**(psi)**	**(psi)**	**(bbl/ft)**	**(in.)**	**(in.)**
[redacted]	[redacted]							
Safety Factor	[redacted]							

(B) Annular Geometry			
Section	**ID**	**MD**	**TVD**
	(in)	**(ft)**	**(ft)**
Drive Pipe	[redacted]	[redacted]	[redacted]
Open Hole	[redacted]	[redacted]	[redacted]

(C) Casing					
Section	**OD**	**ID**	**Weight**	**MD**	**TVD**
	(in)	**(in)**	**(lb/ft)**	**(ft)**	**(ft)**
Surface	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 4-18 – Surface Casing Cement Calculations

(A) Cement			
System	**Top**	**Bottom**	**Volume of Cement**
	(ft)	**(ft)**	**(cf)**
Lead	[redacted]	[redacted]	[redacted]
Tail	[redacted]	[redacted]	[redacted]

(B) Volume Calculations				
Section	**Footage**	**Capacity**	**% Excess**	**Cement Volume**
	(ft)	**(cf/ft)**	**(%)**	**(cf)**
Drive Pipe/Casing Annulus Lead Cement	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Lead Cement	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Tail Cement	[redacted]	[redacted]	[redacted]	[redacted]
Shoe Track	[redacted]	[redacted]	[redacted]	[redacted]

4.4.2.3 Production Casing

Production casing (long-string casing) section will be drilled using a [redacted] bit, and the [redacted] casing will be run from the surface to TD and then cemented to surface. After the surface and production casing are set, four barriers will exist between the USDW and the fluid in the wellbore. This well will not be drilled through the UCI, thus the production casing will not require acid-resistant materials for its construction.

Summaries of engineering calculations for the surface casing are provided in Table 4-19 (A, B, and C), including the cement calculations at Table 4-20 (A and B).

Table 4-19 – Production Casing Engineering Calculations

(A) Production Casing								
Description	Casing Wt.	Depth	Tensile	Collapse	Burst	Capacity	ID	Drift ID
	(ppf)	(ft)	(psi)	(psi)	(psi)	(bbl/ft)	(in.)	(in.)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Safety Factor	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

(B) Annular Geometry			
Section	ID	MD	TVD
	(in)	(ft)	(ft)
Surface Casing	[redacted]	[redacted]	[redacted]
Open Hole	[redacted]	[redacted]	[redacted]

(C) Casing					
Section	OD	ID	Weight	MD	TVD
	(in)	(in)	(lb/ft)	(ft)	(ft)
Intermediate	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 4-20 – Production Casing Cement Calculations

(A) Cement			
System	Top	Bottom	Volume of Cement
	(ft)	(ft)	(cf)
Lead	[redacted]	[redacted]	[redacted]
Tail	[redacted]	[redacted]	[redacted]

(B) Volume Calculations				
Section	Footage	Capacity	% Excess	Cement Volume
	(ft)	(cf/ft)	(%)	(cf)
Surface Casing/Intermediate Casing Annulus Lead Cement	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Lead Cement	[redacted]	[redacted]	[redacted]	[redacted]
Open Hole/Casing Annulus Tail Cement	[redacted]	[redacted]	[redacted]	[redacted]
Shoe Track	[redacted]	[redacted]	[redacted]	[redacted]

4.4.2.4 Centralizers

Centralizer selection and installation for the referenced well will have two separate functions. The bow-spring centralizer design for the [redacted] surface casing will be planned to protect any shallow aquifer zones per state regulations. The specific placement is also to ensure a continuous, uniform column of cement is present throughout the [redacted] annulus. The recommended location will be:

[redacted]

The bow-spring centralizer design for the [redacted] production casing will also be planned to protect any shallow aquifer zones per state regulations. The specific placement is to ensure a continuous, uniform column of cement is present throughout the [redacted] annulus. The recommended location will be:

[redacted]

Final centralizer design for all strings will be finalized at a later date when detailed cement design is also finalized and a stand-off model is completed.

4.4.2.5 Tubing

The tubing string (Table 4-21) will consist of [redacted] tubing and a permanent packer assembly. The tubing string will be used to collect fluid samples above the UCI. WC AZMW-A No. 001 will be equipped with pressure and temperature gauges run on a FOC [redacted], for continuous downhole pressure and temperature monitoring. A cross-coupling cable protector will be mounted to each tubing joint coupling to protect the cable across couplings.

Table 4-21 – Injection Tubing Specifications

Tubing								
Description	**Casing Wt. (ppf)**	**Depth (ft)**	**Tensile (psi)**	**Collapse (psi)**	**Burst (psi)**	**Capacity (bbl/ft)**	**ID (in.)**	**Drift ID (in.)**
[redacted]	[redacted]							
[redacted]								
Safety Factor								

4.4.2.6 Packer Discussion

The production tubing will be run into the well with a [redacted] production packer with premium connections (Figure 4-11).

[redacted]

Figure 4-11 – [redacted] Permanent Packer

4.4.2.7 Wellhead Discussion

The wellhead is designed to accommodate anticipated working pressure. The final pressure rating, currently specified to be [redacted], will be confirmed before beginning the manufacturing process.

The wellhead will be configured as shown in Figure 4-12 (note: the manufacturer may differ from the one shown).

[redacted]

Figure 4-12 – WC AZMW-A No. 001 Preliminary Wellhead Design

4.4.3 Testing and Logging of Above-Zone Monitoring Well During Drilling and Completion Operations

4.4.3.1 Logging Plan

The logging plan is detailed below (Tables 4-22 and 4-23). Harvest Bend CCS will provide a schedule of all logging plans to the UIC Director at least 30 days prior to conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

Table 4-22 – Open-Hole Logging Plan

Hole Section	Logging Suite	Target Data Acquisition	Open-Hole Diameter	Depths of Survey
Surface Casing	[redacted]	[redacted]	[redacted]	[redacted]
Production Casing	[redacted]	[redacted]	[redacted]	[redacted]

Table 4-23 – Cased-Hole Logging Plan

Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension	Depths of Survey
Surface Casing	[redacted]	[redacted]	[redacted]	[redacted]
Production Casing	[redacted]	[redacted]	[redacted]	[redacted]

4.4.3.2 Formation Fluid Testing

Baseline fluid samples will be obtained and tested from the [redacted] formation upon completion of WC AZMW-A No. 001. If pressure anomalies are observed in the [redacted] during injection well operations, additional samples may be obtained and compared against baseline testing results.

4.4.4 Overview of Above-Zone Monitoring Well Completion Program

After setting and cementing the production casing, the production tubing string will be run. The completion program includes the following:

- Make bit and scraper run to TD.
- Run cased-hole logs as described in Table 4-23.
- Test the casing.
- Run tubing and packer to depth.
- Displace the hole with corrosion – resistant packer fluid.
- Set packer and test.
- Perforate the [redacted] formation around [redacted] TVD, specific depths to be determined with open-hole logs [redacted].
- Pump-in test to ensure fluid and pressure communication with the formation. [redacted]

4.4.5 Above-Zone Monitoring Well Operational Strategy

WC AZMW-A No. 001 is engineered to be an above-zone monitoring well. Constant monitoring of downhole pressure and temperature in the [redacted] will be accomplished using a fiber-run pressure and temperature gauges and SCADA systems. The [redacted] formation is the first permeable interval above the UCI, the [redacted]. Temperature and pressure anomalies within the [redacted] are an early indication of injectate from WC IW-A No. 001 moving out of the injection zone. If pressure or temperature anomalies are detected, and deemed not a result of thermal interference from normal operation of the injection well, injection will be halted, and the incident will be evaluated as detailed in the Emergency and Remedial Response Plan (*Section 8*). Following completion of post-injection monitoring requirements, the monitoring well will be sealed per the Injection Well Plugging Plan (*Section 6*).

The location of this project is ideal for carbon sequestration monitoring. By combining the best engineering practices in well design with both a cutting-edge monitoring system and a comprehensive reservoir management strategy, this monitoring well will help ensure the safe storage of CO_2 for an extended period of time.

4.5 <u>USDW Monitor Well</u>

Harvest Bend CCS intends to drill and complete a USDW monitoring well [redacted]. WC GW-A No. 001, [redacted], will monitor the lowermost USDW intervals near the injection well. WC GW-A No. 001 will be situated in the currently predicted carbon and critical pressure boundaries and will monitor for signs of CO_2 escaping up into USDWs. This well will not be drilled through the UCI, thus it will not require acid-resistant materials for its construction.

The proposed preliminary design for WC GW-A No. 001 is depicted in Figure 4-13.

[redacted]

Figure 4-13 – WC GW-A No. 001 Wellbore Schematic

4.5.1 Formation Fluid Testing

Baseline aquifer water samples will be obtained and tested from the lowermost USDW interval upon completion of WC GW-A No. 001. As discussed in *Section 5.5.3* of the Testing and

Monitoring Plan, WC GW-A No. 001 will be a critical part of monitoring the ongoing CO_2 storage operations.

4.5.2 USDW Monitoring Well Operational Strategy

WC GW-A No. 001 is engineered to be a USDW monitoring well. Representative aquifer water samples will be obtained quarterly and compared against baseline sampling and fluid testing results, to verify that injectate is not leaking into the USDW. If fluid sample anomalies are detected, injection will be halted, and the incident will be evaluated as detailed in the Emergency and Remedial Response Plan (*Section 8*). Following completion of post-injection monitoring requirements, the USDW monitoring well will be sealed as per the Injection Well Plugging Plan (*Section 6*).

Appendix D: Well Construction Schematics and Procedures

- Appendix D-1 WC IW-A No. 001 – Wellbore Schematic (Initial Completion)
- Appendix D-2 WC IW-A No. 001 – Detailed Drilling Procedure
- Appendix D-3 WC AZMW-A No. 001 – Wellbore Schematic

Appendix E: Casing and Tubing Alloy Selection Report