Appendix A

This appendix provides supplemental information pertaining to the long-term storage (sequestration) of CO_2 that will occur as a result of the Oxy CO_2 Project. Data presented in this appendix is intended to represent not only the initially proposed permit area, but the full life of the project.

CO_2 EOR and Storage Project

Occidental of Elk Hills, Inc. (OEHI) intends to implement CO_2 Enhanced Oil Recovery (EOR) to increase oil and gas production and reserves from the Stevens reservoirs within the Elk Hills Unit. The OXY CO_2 Project will utilize CO_2 from the Hydrogen Energy California (HECA) project, which will be located near the Elk Hills Unit. The HECA project will generate CO_2 from an Integrated Gasification Combined Cycle (IGCC) power plant. During normal operations, the HECA project is expected to deliver an annual average rate of a 110 million standard cubic feet per day (MMSCF/d) of CO_2 (approximately 2.2 million tons per year) to Elk Hills, where it will be utilized in a miscible EOR recovery process.

CO_2 EOR

Permitting of CO_2 injection associated with EOR operations is well established and regulated by the California Division of Oil, Gas and Geothermal Resources (DOGGR) under authority granted through EPA's existing Underground Injection Control (UIC) Class II regulations. Under California law, DOGGR has responsibility for permitting injection and extraction wells and associated well facilities for the OXY CO_2 Project. . The wells to be used for CO_2 injection are Class II injection wells. DOGGR has been given primacy to permit Class II injection wells in the state of California under the Underground Injection Control ("UIC") program pursuant to Section 1425 of the Federal Safe Drinking Water Act, 42 U.S.C. § 300h-4, *See* 48 Fed. Reg. 6336 (Feb. 11, 1983). The wells and associated well facilities will be permitted pursuant to authority provided to DOGGR in the Public Resources Code and in accordance with applicable DOGGR regulations. *See generally* Cal. Pub. Res. Code Division 3, Chapter 1 and 14 Cal. Code Regs. Division 2. DOGGR has statutory responsibility under Division 3 of the Public Resources Code to regulate all oilfield operations in the State of California.

The UIC regulations have been developed to ensure the protection of underground sources of drinking water (USDW) and safety of the public. The Elk Hills Field is unique in that the only aquifer that meets the total dissolved solids criteria for being an underground source of drinking water is exempt from UIC regulation. This exempt reservoir is defined as a producing unit in the California Oil and Gas Fields (Vol 1). In 2004, DOGGR granted permit #22800022, allowing injection of disposal water into this reservoir.

CO_2 Storage

In addition to satisfying the above described EOR permitting requirements, OEHI has considered the sequestration aspects of EOR including:

- **Reservoir (Site) Characterization -** confirming isolation of injectant below the lowermost USDW, validating injection and storage capability of the storage site, identifying potential leakage pathways, and assessing risk potential;
- **Well and Facility Operations -** identifying surface and subsurface equipment requirements, developing and implementing programs for mechanical integrity and safe operation of equipment, and identifying specific injection limits to maintain the integrity of the reservoir and confinement zone;
- **Monitoring, Measurement and Verification (MMV) -** assessing the performance of the sequestration site (geology and technology), and validating anticipated behavior;
- **Closure** - developing and implementing programs for plugging and abandonment, identifying reservoir characteristics required to demonstrate non-endangerment and developing and implementing a post-injection MMV program to demonstrate non-endangerment.

The above described activities represent various components of a single strategy that will ensure safe and secure implementation and operation of the Oxy CO_2 Project at Elk Hills Field. The following sections further discuss specific activities related to these individual components.

Reservoir (Site) Characterization

Reservoir Containment

A primary objective of existing UIC Class II rules is to ensure containment of injected CO_2 (and water) within the target formation. Evaluation of the risk associated with potential leakage pathways (if any) verifies the appropriateness of the site for CO_2 injection. The reservoir characterization work (documented in the injection permit request) includes analysis of:

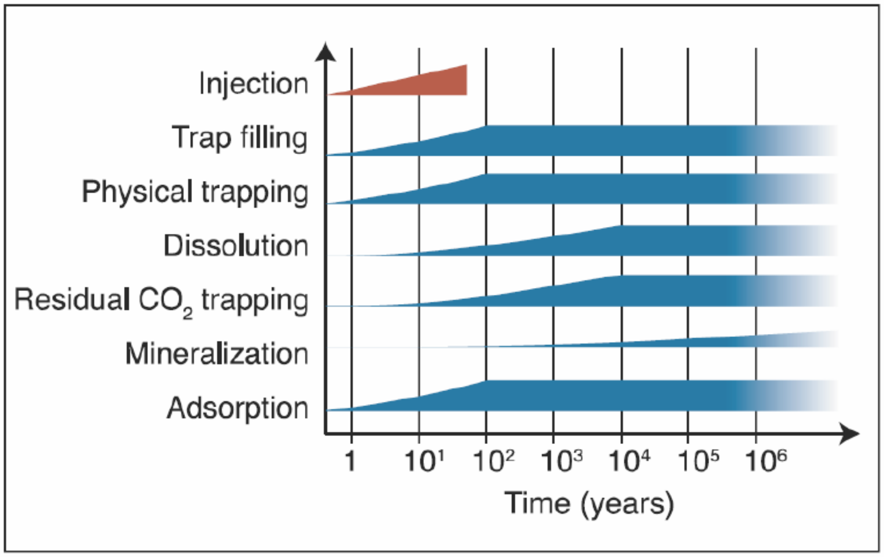
- CO_2 injection pilot that confirmed containment of CO_2 in the Stevens reservoir
- Stratigraphy, structure, depth, thickness, pressure, porosity, geomechanical and fluid flow properties of the storage reservoirs and confining zone
- Sealing capacity of the confining zone
- Natural and induced seismicity (See: HECA regional seismicity study for the Elk Hills Field in Appendix F of HEI AFC Application)
- Absence of transmissive faults that intersect the confining zone in an area which may be impacted by CO_2
- Well construction and plugging history of all wells which penetrate the confining zone

- Compositional analysis of injection and reservoir fluids.
- Evaluation and modeling of all potential CO_2 trapping mechanisms.

CO_2 Trapping Mechanisms
In addition to physical trapping from the confining zone, various other mechanisms exist that will trap CO_2 in the Stevens reservoirs. The key trapping mechanisms that occur in the subsurface to indefinitely sequester the CO_2 include physical trapping, residual trapping and geochemical trapping.

- Physical trapping (and trap filling) retains the CO_2 in the formation using structural and stratigraphic traps with low permeability formations and faults. Physical trapping of the CO_2 is provided by the same impermeable caprock seal described in the permit, that has trapped the oil and hydrocarbon gases for millions of years.
- Residual trapping of the liquid or gaseous CO_2 occurs as a result of capillary forces permanently retaining some of the CO_2 as disconnected droplets. Residual trapping is analogous to residual oil saturation (i.e. “trapped” oil) that remains after an oil reservoir is swept with injected water.
- Geochemical trapping describes a series of reactions of CO_2 with natural fluids and minerals in the target formation, principally consisting of CO_2 dissolution in brine and oil (i.e., solubility trapping), CO_2 precipitation as mineral phases (i.e., mineral trapping) and CO_2 adsorption onto mineral surfaces. Scientific research is continuing to increase the understanding of the chemical processes involved in geochemical trapping.

These trapping mechanisms operate on different time scales, beginning with initial injection of CO_2 and have different capacities to trap CO_2. The following schematic depicts the various trapping mechanisms and time horizons.



Source: Metz, B.E.A., 2005, *Special Report on Carbon Dioxide Capture and Storage*. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, England. <http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_Chapter4.pdf>.

Schematic shows the time evolution of various CO_2 sequestration mechanisms operating in deep formations during and after injection. Time is shown on an exponential scale were 10^1 is 10 years, 10^2 is 100 years, and so on.

Reservoir Capacity

In addition to data presented in the DOGGR UIC permit application confirming containment of CO_2 in the Stevens reservoirs, OEHI's site characterization work confirms that the Stevens reservoirs have sufficient volume to store all expected CO_2 deliveries from the HECA project. Historic Elk Hills production records and injection data show that the volume of oil, gas, and water already extracted from the target injection zones exceeds the volume required to store the cumulative (full-life) volume of CO_2 expected from the HECA Project. In addition, oil production during the CO_2 EOR project phase will create further capacity for CO_2 storage. Available capacity is demonstrated in the following tables.

- Stevens Pore Volume Capacity

  The Stevens reservoirs within the 31S and North West Stevens (NWS) structures have been identified as the EOR and storage reservoirs for the Oxy CO_2 Project. These reservoirs contain sufficient pore volume to occupy the injection of more than twenty years of expected CO_2 delivery from the HECA Project.

	Billion Reservoir Barrels
31S Structure - Total Stevens Pore Volume:	> 7.5
Required Storage Capacity for 20 Years of Expected CO2 Injection:	< 1.0

- Cumulative voidage to date, from 31S and NWS Stevens reservoirs

  The table below shows that the net cumulative fluid volume produced to date, from Stevens reservoirs on the 31S and NWS structures, exceeds the volume required to store the CO_2 volume expected from the HECA Project.

	Billion Reservoir Barrels
Cumulative Fluid[1] Volume Produced:	> 3.4
Cumulative Fluid[1] Volume Injected:	< 2.1
Cumulative Net Fluid[1] Volume Produced:	> 1.3
Required Capacity to Storage 20 Years of Expected CO_2 Injection:	< 1.0

[1] Includes oil, gas, and water

In addition to the available storage volume calculated above, during EOR operations the production of oil, gas, and water will create further reservoir voidage that will allow injection and storage of additional CO_2.

Well and Facility Operations

Occidental Petroleum Corporation is one of the largest and most respected CO_2-EOR operators in the world and is the largest oil producer in the Permian Basin, operating many CO_2-EOR projects that include thousands of wells. This expertise will be utilized in planning and executing the proposed CO_2 injection project. A primary objective during all CO_2-EOR well operations is to ensure that wells are constructed in a fashion that prevents fluids from entering a USDW and injection is controlled such that injected fluids are confined within the injection interval, such that the confining layer is not damaged. OEHI operations have addressed the following items:

- Regulation of injection pressure and volume
- Analysis of the chemical, physical and radiological and biological characteristics of the injection fluid
- Regulation of the depth and method of injection
- Regulation of wellbore construction covering hole diameter, casing and cementing materials, depth of perforation and isolations
- Specific logging and testing requirements for newly constructed wells.
- Preparation of contingency plans to cope with well shut-ins or failures
- Mechanical integrity testing

Monitoring, Measurement and Verification (MMV)

MMV will be an integral part operating the Oxy CO2 Project. The MMV requirements will achieve key sequestration objectives: (1) ultimate containment of the stored CO_2; (2) protection of human health and the environment; (3) confirmation that the injected CO_2 is behaving as planned; and (4) fulfillment of all applicable regulatory requirements.

Elk Hills benefits from the presence of numerous producing wells, including many wells producing from horizons above and below the Stevens reservoirs. These wells will act as observation points to provide immediate evidence of predicted and/or unpredicted subsurface CO_2 movement. Observed real-time data from these wells will be gathered from existing and new wellbores through the following processes:

- Monitoring of wellhead and annular pressures of wells completed in the Stevens reservoirs, supplemented by downhole pressure and temperature where available.
- Monitoring of wellhead and annular pressures of wells completed in reservoirs vertically adjacent to the Stevens reservoirs, supplemented by downhole pressure and temperature measurements in these offset reservoirs where available.
- Well integrity monitoring, including cement bond logging upon initial well completion.
- Produced fluid compositional analysis.

In addition to the large amount of direct MMV data that will be gathered, OEHI will engage in the follow containment verification activities:

- Characterization of rock stress and strength through acquired geomechanical data.

- Material Balance analysis.
- Static and dynamic subsurface modeling to characterize migration of injected fluids through the reservoir.
- Monitoring plan for collection of subsurface pressure, reservoir fluid chemistry and other data as necessary to demonstrate and predict behavior of the injected CO_2.
- A leak detection plan that will include monitoring of wells and produced fluids in reservoirs adjacent to the Stevens reservoirs to provide early detection of any CO_2.

Closure

The closure phase of a CO_2 EOR and Sequestration project consists of site decommissioning, well plugging and abandonment, and appropriate post-injection site care and monitoring to demonstrate that the injected CO_2 is properly contained within the confinement zone and is not endangering USDWs, human health or the environment. Existing Class II EOR Closure requirements cover plugging and abandonment of wells. In addition, site closure at the Elk Hills Field will be conducted pursuant to a DOGGR approved performance-based post-injection site care and closure plan specifically tailored to the Elk Hills field. Anticipated elements of the plan include:

- Continued monitoring in a portion of the wells during the closure period to demonstrate non-endangerment.
- For all other wells, plug and abandon according to regulatory standards to ensure project integrity, unless site-specific conditions warrant special materials or procedures. (Perform a final assessment of the cement bond log across the primary sealing interval of all operational wells within the injection footprint prior to plugging, as well as standard mechanical integrity and pressure testing.)
- Assemble a comprehensive set of data describing the location, condition, plugging, and abandonment procedures, and any integrity testing results for wells that will be potentially affected by the storage project.
- Satisfactory completion of post-injection monitoring to demonstrate:
    - the estimated magnitude and extent of the project footprint (CO_2 boundaries and area of elevated pressure);
    - that CO_2 boundaries and pressure changes match predictions;
    - the estimated location of any free phase CO_2 based on measurement;
    - either (a) no evidence of significant leakage of injected or displaced fluids into formations outside the confining zone, or (b) the integrity of the confining zone;
    - that, based on the most recent geologic understanding of the site, including monitoring data, the injected or displaced fluids are not expected to migrate in the future in a manner that encounters a potential leakage pathway; and
    - that wells at the site are not leaking and have maintained integrity.
- The site-specific risk assessment will be updated based on operational data and observations during closure.